WATER QUALITY ANALYSIS OF THE RARITAN-LOWER BAY SYSTEM

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OF THE
RARITAN BAY SYSTEM

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I. Introduction

The Raritan Bay, Lower Bay and Sandy Hook Bay combine to form a triangular body of interstate tidal water that extends inland approximately 13.5 miles between Staten Island, New York on the northwest, and the New Jersey shoreline to the south. At the western extremity, the Raritan River and Arthur Kill join the Bay while on the east the Raritan Bay System abuts the ocean between Sandy Hook and Coney Island (Fig. 1). The New York-New Jersey state boundary passes approximately from east to west through the middle of the Bay until it swings northerly up the middle of the Arthur Kill. The entire system is estuarine and is characterized by tidal oscillations and current reversals which provide the major dispersive mechanisms within the system.

The waters of this study area are presently utilized for industrial water supply, navigation, commercial fin and shellfishing and a variety of recreational activities. However, full utilization of these waters is presently restricted by unsuitable water quality resulting from the impact of the five (5) principal wastewater sources affecting this estuary:

a). The waste loading entering the Bay from the Arthur Kill;
b). The degraded water quality which enters through the Narrows which is due to wastewater discharges in the New York Harbor System;
c). The waste loading from the Middlesex County Sewerage Authority (MCSA) treatment facility;
d). Other point source waste loadings to Raritan Bay in the vicinity of the MCSA discharge; and
e). The water quality at the mouth of Raritan River which results from upstream discharges.

The following report is an effort to describe, on a preliminary basis, the conceptualization of the Raritan Bay System as a unique mathematical entity wherein the observed naturally occurring hydrodynamic and water quality phenomena can be reproduced. The analysis hopefully will provide greater understanding and insight into both the transport and physical phenomena which dominate the system, such that the model can be utilized ultimately as a predictive tool for subsequent evaluation of proposed pollution abatement alternatives. The procedures followed within the analytical framework of the report thus allow evaluation of proposed siting for the MCSA outfall given the appropriate data relative to both this discharge and the other major discharges to the Raritan Bay System. The water quality projections thus obtained represent both tidally and spatially averaged values over specific segments of the system.

II. General Description of Raritan Bay System:

Physical Features

The estuarine system, collectively referred to as the Raritan Bay System, may be divided into three(3) general and distinct hydrologic areas -- Raritan Bay is located in the western portion of the System, the Lower Bay stretches from Point Comfort eastward to Sandy Hook, while Sandy Hook Bay is located generally southeast of the Point Comfort-Sandy Hook traverse (Fig. 1.).

The entire System is a shallow estuary, having a mean depth of less than 15 feet and a surface area of 1670 x 10^6 square feet. The floor of the Bay slopes fairly uniformly and gently toward the central axis where the depths are approximately 22 feet in Raritan Bay and 28 feet in Lower Bay. Maximum depths in the Bay are on the order of 30 feet, excluding the major shipping channels which have depths ranging to 40 feet.

The System is characterized by a number of peripheral shoals located both along the Staten Island and the New Jersey south shore beaches - a factor which is quite significant with respect to the resultant hydrodynamic patterns exhibited within the Bay.

Hydrology

Examination of the hydraulic, tidal and geometric structures of the Raritan Bay System suggests an extremely complex and interacting natural water system governed not only by the effects of the interconnected waterways but also by such external forces as wind, tides and tidal lags. Accordingly, the initial efforts of the study were directed largely towards a determination of the movement of waters both within and across the defined boundaries of the system. Through the review of past survey and study results, the probable flow paths for specific pollutant parameters were both defined and quantified to the degree of accuracy considered necessary for adequate representation of the System.

The Raritan Bay System is bounded by four(4) arbitrary traverses at which predetermined water quality constituents were designated. The locations of these boundaries are as follows: (1) across the mouth of the Raritan River, (2) across the mouth of the Arthur Kill, (3) across the Verranzano Narrows, and (4) along a traverse between Norton Point, N.Y. and Sandy Hook, N.J. (Fig. 2).

Raritan Bay is one of a collection of shallow bays and lagoons which characterizes the Atlantic Coast of New Jersey. It is typical in that it has a roughly triangular shape and its hydraulics are governed primarily by wind and tidal mechanisms. Source waters which are largely responsible for the general flow patterns within the System enter the basin from opposite ends - from the Raritan River on the west and through the Verrazano Narrows and Lower Bay* on the east. The general tendency within the System is thus towards the creation of a discernible large scale counterclockwise gyre of slowly circulating water masses (Jeffries, 1962). The net result of this pattern is the establishment of a series of physical-chemical gradients directed along and at right angles to the axis of the estuary - an observation which substantiates the need for multi-dimensional modeling of the Bay.

The Bay is also the recipient of a number of smaller direct freshwater inputs from both natural tributaries and artificial sources. Aside from the municipal-industrial discharges which are discussed in greater detail in later sections, the major remaining natural advective sources are the Arthur Kill, Matawan Creek, and the Navesink River. The most significant of these, the Arthur Kill, does not represent a substantial source of freshwater but rather acts a large surge basin contributing to the complex mixing processes existing at the western end of the Bay. The major significance of this tributary lies in the fact that it represents a large source of both biodegradable and potentially toxic substances which are dispersed throughout the Kill and eventually into the western portion of the Raritan Bay System. The remaining Matawan Creek and Navesink River inputs do not have any appreciable effect on the circulation patterns within Raritan Bay outside their immediate confluence areas due largely to their insignificant flows and their remoteness from the deeper portions of the Bay.

The general counterclockwise flow patterns exhibited within the Bay itself have been frequently substantiated by observations of salinity, iron, and suspended solids profiles. These past surveys have indicated that flushing in Raritan Bay System is accomplished by a net tidal drift which is westward along the north shore and eastward along the south shore (WHOI, 1949). Many of the specific details concerning the general circulation pattern are as yet undefined and therefore, unpredictable. Certain portions of the Bay, most notably, the western end of the System, for example, are known to exhibit small scale tidal reverses without any apparent relationship to the larger semi-diurnal tidal flood and ebb. However, a number of know hydraulic phenomena resulting from the interaction of the aforementioned general circulation patterns and the Bay structure are predictable.

It is known that the southwesterly thrust of higher salinity waters flooding into the Raritan Bay System from the Verrazano Narrows-Lower Bay area along the Staten Island shoreline is impeded and eventually diverted along a southerly course in the vicinity of Great Kills

*The source water across this boundary is actually a mixture of Hudson River water and sea water having an average salinity of 27 0/00.

Harbor due to the influence of Old Orchard Shoal. This shoal area is in effect a sluggish eddy which acts as a barrier between the Raritan Bay and Hudson River circulation patterns almost as effectively as though it were dry land (WHOI, 1949). The resultant diversion of this inland (Hudson) thrust appears to exert an action which accelerates the seaward movement of (Raritan) freshwater along the south shore of Raritan Bay while at the same time damming back the waters accumulated in the head of the Bay area (Jeffries, 1962). This phenomena has been evidenced somewhat by the observation of intertidal current reversals, the existence of many small scale eddy formations and the relative lateral, longitudinal and vertical uniformity throughout the western Bay area.

The effect of the Raritan River influent on Bay circulation patterns is limited largely to the south shore area of the Bay. The lateral gradients in such parameters as salinity and turbidity during high flow periods have established the general excursion of the Raritan River along this section of the Bay. It has been noted likewise, that the ebb currents immediately north of Point Comfort are regularly stronger than the flood indicating a definite net drift seaward past this point in particular and along the south shore in general. The seaward drift due to this Raritan influence is in the order of 0.5 miles per day west of Conaskonk Point with a range varying from 0.25 to 0.5 miles per day. The net detention time within the head of the Bay itself is in the order of 6 tidal cycles or approximately 3 days under average flow conditions (Ketchum, 1950). This detention is consistent with the reported 7 day travel time from the Raritan River confluence to Conaskonk Point (WHOI, 1949) and the estimated overall flushing time of 32-42 tidal cycles or 16-21 days for the entire Bay System (Jeffries, 1962). East of the Conaskonk Point-Point Comfort area, the bay widens and deepens markedly enough to allow greater mixture of the Raritan River influent with large volumes of the diverted Hudson River-Lower Bay water masses. Most of this mixture finds its way seaward around Sandy Hook, however, at certain times some of this volume is likely dispersed back into the Raritan Bay System along with the indraft along the Staten Island shoreline.

The hydrodynamics of Sandy Hook Bay have not yet been adequately defined, however, there are indications that no waters diluted by the Raritan River flow directly into Sandy Hook Bay after rounding Point Comfort. It is quite likely that the effect of the Raritan influent on this portion of the System is governed largely by dispersion mechanisms dependent on wind and tidally induced parameters. Measurements within the Bay itself reveal only weak and variable direction currents not specifically correlated with the larger scale tidal oscillations of the Raritan-Lower Bay System. There is evidence that a steady northward drift occurs along the west shore of Sandy Hook - a result undoubtedly of the influence of the Navesink influent on this portion of the Bay. It is likely that a small scale counterclockwise gyre similar to the larger pattern exhibited in the Bay proper exists in this sector of Sandy Hook Bay due to the Navesink influent and possible Coriolis effects. Past studies concerned with the hydraulics of the Raritan Bay System indicate that, in general, Sandy Hook Bay itself, is a relatively stagnant portion of the System which is largely unaffected by the general hydraulic patterns prevalent in the central Bay area.

Along the traverse extending from Sandy Hook to Norton Point, it has been noted that ebb tides are generally stronger and flow somewhat longer than the flood tides - an observation which is consistent with the general Hudson seaward drift along Ambrose Channel. Tidal velocities and the attendant dispersion characterics are greater along this interface than in any other area of the Bay with the exception of the Verrazano Narrows. Average and peak tidal velocities along this interface are in the order of 1.7 and 4.2 fps, respectively, (U.S.G.S. Current Charts, 1956) as compared to an average tidal velocity throughout the Raritan Bay System of 0.8 fps(Hydroscience, 1968). It should be noted that, with the exception of this turbulent outer boundary area, the tidal velocities and tidal range generally increase as the Bay System narrows toward the western end; the maximum velocity readings being 1.0 fps off Point Comfort, 1.5 fps at Great Beds Channel, and 2.5 fps in the lower Raritan River (WHOI, 1949). Conversely, tidal velocities have been observed to generally decrease along nearshore areas due to extensive shoaling and are frequently so weak(less than 1/6 knot) that the direction of tidal flow becomes more variable. This phenomena is particularly true in the western end of the Bay where intertidal reverses and resultant eddies often retard exchange of water over the shoals along the south shore. The pattern of circulation in the Lower Bay-New York Bight boundary vicinity has not been specifically defined, however, salinity profiles indicate that less saline water leaves the Bay System close around Sandy Hook while that from the Hudson River flows out along Ambrose Channel. Higher salinity waters occupy the central region of this coastal boundary indicating generally lesser freshwater extrusion in this area than across the Ambrose Channel-Sandy Hook sectors.

In summary, the Raritan Bay System may be considered a wide, generally shallow, estuarine system dependent largely upon the influence of the widely dispersed source water inputs and the complex interaction of its tributary channels, variable wind patterns, and independent hydraulic parameters governed by tidal phenomena. It is characteristic in that saline waters generally penetrate further upstream along the right shore(looking upstream) than along the southern end of the Bay--a phenomena which is frequently observed in northern hemisphere estuaries.* Yet it is unique in that, although it is a predominantly dispersive system, it exhibits both large and small scale circular water movements which at times tend to prevent the intrusion into or entrap pollutants within certain areas of the Bay. Thus, the joint consideration of outfall siting and Bay hydrodynamics is of paramount importance if the protection and enhancement of Raritan Bay water quality is to be achieved.

*This description also applies but is reversed in southern hemisphere estuaries. (Ketchum, 1951).

Existing Waste Sources

At the present time there are a total of twenty-three(23) known point waste sources which discharge to the Raritan Bay System. Fourteen(14) of those sources are located in New Jersey, predominantly along the south shore of the Bay, while the remaining(9) are located in Staten Island, N.Y.. There are twenty-one(21) municipal wastewater discharges to the Raritan Bay System which constitute the major point sources in the study area. The two(2) industrial sources, International Flavors and Fragrances and S.S. White, Inc., represent only minor discharges relative to the larger municipal sources. The ten(10) largest wastewater discharges to the Raritan Bay System and pertinent discharge characteristics have been listed for reference in Table 1. The location and magnitude of each has also been included in Fig. 2. All other point sources to the System have been excluded from the model analysis due largely to their relatively insignificant flows or organic loadings.

The effluent data which was assembled for each particular discharger was obtained from a number of independent sources thereby assuring more accurate and reliable estimates. The major data sources utilized are listed as follows: 1) the EPA STORET system, 2) Interstate Sanitation Commission (ISC) Annual Reports, 3) the South Raritan Bay Interim Basin Plan (prepared by the New Jersey State Department of Environmental Protection), 4) Raritan Bay Project results (FWPCA, 1968), and 5) Refuse Act Permit Program files.

The Middlesex County Sewerage Authority(MCSA) discharge represents by far the largest point source discharge within the Raritan Bay System. The estimated present discharge of 240,000 #/day BOD_5 and 405,000 #/day ultimate oxygen demand (UOD) account for approximately 90.4% and 89.4% of the total load of each respective constituent discharged to the Bay from all known point sources. The actual MCSA discharge site is located approximately 1000 feet south of Great Beds Light in the western end of the Bay and is unique in that a dredged dispersion basin has been provided to a depth of 35 feet in an otherwise shallow region of the Bay which averages about 9.0 ft. mean sea level(MSL) depth. This source, in conjunction with the second major point source, the City of Perth Amboy, represents over 96% of the total BOD_5 loading to the Raritan Bay System from all identified municipal and industrial sources.

The majority of the existing municipal discharges to the Bay receive only primary treatment with the two(2) exceptions being the Oakwood Beach facility (secondary) and the Tottenville, S.I. discharges (untreated).

Finally, it should be noted that the two(2) largest waste(UOD) sources in the Bay System are discharge to the western end of the Bay in an area with very limited capacity to assimilate any wastewater discharges due to the poor hydrodynamic, physical and flushing characteristics which are unique to the portion of the Bay. The

TABLE 1.
Existing Municipal Waste Sources
Raritan Bay System

Waste Source	Trt. Level	Flow (MGD) 1/		Effluent Loadings (#/day)			
		Design	Actual	BOD_5 2/	NH_3 2/	UOD 3/	Chlorides 2/
1) Middlesex Co. S.A.	Pri	72.0	72.0	240,000 (400)	9950 (16.6)	405,000.	174,960 (292)
2) Perth Amboy	Pri	10.0	6.0	17,300 (290)	1000 (20)	26,100.	4670 (90)
3) Oakwood Beach	Sec	15.0	13.0	3,800 (35)	1190 (11)	11,050.	34,690 (320)
4) Keansburg	Pri	5.0	2.0	1,200 (72)	125 (7.5)	2,363.	2,670 (160)
5) South Amboy	Pri	1.0	0.9	1,580 (210)	225 (30)	3,377.	450 (60)
6) Keyport	Pri	2.9	0.7	585 (100)	82 (14)	1,244.	584 (100)
7) Highlands	Pri	1.2	.4	500 (150)	91 (27)	1,160.	---
8) Atlantic Highlands	Pri	0.6	.3	292 (117)	29. (11.7)	568.	---
9) Sayreville-Morgan	Pri	0.3	.15	268 (214.)	49. (39.)	622.	---
10) Madison Twsp.	Pri	1.4	0.6	584 (117)	125	1437	---
Total			97.05	266,109	12,866	452,921	218,024

Pri = Primary Treatment
Sec = Secondary Treatment
1/ = Flow data from Raritan Bay-South Shore Interim Basin Plan and Interstate Sanitation Commission Annual Report (1971).
2/ = BOD_5, NH_3 and Chloride data from STORET system.
3/ - Ultimate Oxygen demand from Equation: $UOD = 1.5\ BOD_5 + 4.5\ NH_3$
( ) = effluent concentrations in mg/l

analyses presented in later sections of this report will investigate to a greater extent the significance of these phenomena with respect to the site selection for the MCSA outfall.

III. Mathematical Model Theory and Derivation*

The technique used to evaluate the steady-state or tidally averaged distribution of water quality constituents in Raritan Bay is a special finite difference approximation to the ordinary differential equations describing the conservation of mass in an estuary(Hydroscience, 1970). The natural water system, in this case, the Raritan Bay System, is subdivided into a number of individual finite water parcels which are considered to be completely mixed but inter-dependent water bodies (Fig. 3). No gradients are permitted within any individual segment. A steady-state mass balance is then formulated around each of these interconnected segments which results in a set of differential equations, which are then solved simultaneously using a Gauss-Seidel elimination technique.

The actual vehicle for applying this technique is a digital model (EPA, 1973) adapted from a program developed originally by the aforementioned consultant. Although a detailed description of the program and the underlying theory are beyond the scope of this report, a brief discussion of the theory has been included for reference and background information.

One-Dimensional Analysis (Steady-State)

In the one-dimensional analysis, a length of estuary is subdivided into n sections, each of which are assumed to approximate completely mixed volumes(Fig. T-1). In the segmentation scheme, the numerical designation is

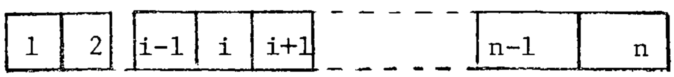

Figure T-1.

usually started at the upstream end of the system and ascends towards the ocean boundary. For the particular model utilized in the analysis, a mass balance for each of the individual segments is written as follows:

$$V_i \frac{dc}{dt} = Q_{i-1,i}(\alpha_{i-1,i} C_{i-1,i} + \beta_{i-1,i} C_i) - Q_{i,i+1}(\alpha_{i,i+1} C_i + \beta_{i,i+1} C_{i+1})$$
$$+ E'_{i-1,i}(C_{i-1} - C_i) \qquad + E'_{i,i+1}(C_{i+1} - C_i)$$
$$- K_i V_i C_i \qquad + W_i \qquad , \quad i=1,2.....n \qquad \text{(T-1)}$$

*condensed from Estuarine Modelling An Assessment, prepared for the EPA Water Quality Office by Tracor, Inc., 1971.

where

V_i = volume of segment i
E_{ij} = E_{ij} A_{ij}/((Li+Lj)/2)= bulk dispersion coefficient between section i and j.
α_{ij} = finite difference weight, a function of the ratio of flow to dispersion.
B_{ij} = α_{ij} -1
Q_{ij} = net nontidal flow from segment i to segment j.
C_i = concentration of pollutant constituent in segment i.
K_i = first order reaction coefficient in segment i for water quality constituent, C
A_{ij} = cross-sectional area between segments i and j.
L_i = characteristic legnth of segment i.
W_i = source or sink of water quality constituent C.
n = total number of segments.

The first two terms on the righthand side of Equation (T-1) represent the mass of constituent c entering (from segment i-1) and leaving (to segment i+1) due to advective or non-tidal transport. Elements three and four in the equation indicate that portion of the constituent c dispersed into or out of segment i due to existing concentrations of the constituent in adjoining segments i-1 and i+1 and the longitudinal mixing provided by the semi-diurnal tidal reverses. Term five in the equation represents the loss of constituent c due either to decay and/or physical sedimentation as incorporated in the first order decay coefficient, K_i. The sixth and final term includes all other sources or sinks of constituent c within section i.

If all terms containing items c_{i-1}, c_i or c_{i+1} in Equation (1) are grouped on the left side the general equation

$$A_{i,\ i-1}\ C_{i\ -1} + A_{ii}\ C_i + A_{i,\ i+1}\ C_{i+1} = W_i \qquad \text{(T-2)}$$

results, where the parameter, a, has the dimensions (L^3/T) and is a function of V, Q, E, K and A . A total of n equations of this type may be written for the system and can be used to construct a matrix of the form

$$(A)\ (c) = (W) \qquad \text{(T-3)}$$

where A is an n x n matrix consisting entirely of system parameters defining both the physical and hydraulic nature of the particular estuary under analysis. Matrix (W) is an n x 1 matrix representing specific sources (waste inputs) and sinks within the individual segments. The response matrix (c) represents the projected steady-state instream concentrations of constituent c in each segment. The solution for the response matrix (c) is thus reduced to the solution of n simultaneous equations which may be represented as follows:

$$(c) = (A)\ (W) \qquad \text{(T-4)}$$

The matrix (A) has a particular form for the one-dimensional estuary. This form is known as a tri-diagonal matrix where only the main diagonal and the diagonals above and below the main diagonal appear in the matrix. All other elements are zero. This is a feature which permits special efficient computing programs for determination of the inverse of matrix (A) . One can of course use other methods of solution for simultaneous equations to obtain the concentrations in each section.

The inverse matrix $(A)^{-1}$ is termed a steady-state response matrix and represents the responses in c due to the discharge of material of a unit amount into each section. This can be seen by

$$(A) \quad (c) = (I) \tag{T-5}$$

$$(c) = (A)^{-1} \quad (I) \tag{T-6}$$

where (I) is the identity matrix and (c) is now an n x n matrix. The first column of (c) then represents the response over all sections due to a unit steady input into the first section; the second column of (c) represents the response over all sections due to a unit steady input into the second section, and so on.

For two-stage consecutive reactions, as in the case of carbonaceous BOD-DO, a similar procedure is followed. A matrix (B) is generated; the only difference between (A) and (B) is the reaction coefficients on the main diagonal. Thus, if D stand for DO deficit and L for BOD, the matrix equation for DO is

$$(B) \quad (D) = (S) \tag{T-7}$$

where (S) is the vector or sources and sinks. If only the BOD sink of DO is considered then

$$(B) \quad (D) = (VK_dL) \tag{T-8}$$

where K_d is the deoxygenation coefficient. Multiplying by $(B)^{-1}$ gives

$$(D) = (B)^{-1} \; (VK_dL) \tag{T-9}$$

where K_d is the deoxygenation coefficient. Multiplying by $(B)^{-1}$ gives

$$(D) = (B)^{-1} \; (VK_dL) \tag{T-10}$$

But since

$$(L) = (A)^{-1} \; (W) \tag{T-11}$$

then

$$(D) = (B)^{-1} \; (VK_D) \; (A)^{-1} \; (W) \tag{T-12}$$

where (VK_d) is an n x n diagonal matrix. Equation (T-7) indicates the method of solution for two stage consecutive reactions.

Two Dimensional Analysis (Steady-State)

The steady-state mass balance equation for single-stage non-conservative substances in two dimensions is given by

$$\frac{\partial c}{\partial t} = 0 = \frac{\partial}{\partial x}(vc) - \frac{\partial}{\partial y}(-vc) + \frac{\partial}{\partial x}\left(E_x \frac{\partial c}{\partial x}\right)$$

$$+ \frac{\partial}{\partial y}\left(E_x \frac{\partial c}{\partial y}\right) - K(X,Y)c \qquad \text{(T-13)}$$

where u and v are the velocities in the x- and y- direction and similarly E_x and E_v are the tidal dispersion coefficients in the x- and y- direction. These two directions can be interpreted in terms of either the horizontal plane (x - length, y - width) or the vertical plane (x - length, y - depth). General analytical solutions of Equation (T-13) for arbitrary coefficients are not available. Hence, in water quality modeling, a finite section approach can be used.

One approach to solving Equation (T-13) is to utilize the notion of a sequence of completely mixed sections discussed in terms of the one-dimensional estuary previously. For the multi-dimensional steady-state case, a mass balance around a finite section is surrounded by segment j is given as shown in Figure T-2.

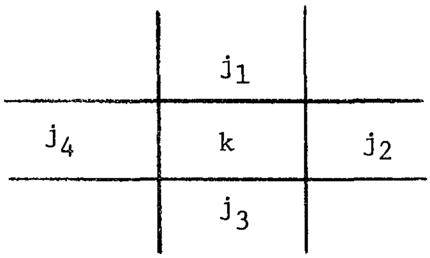

Fig. T-2; -Segmentation in two dimensions.

$$V_k \frac{dc}{dt} = 0 = \Sigma(-Q_{kj}(\alpha_{kj} c_k + \beta_{kj} C_j) + E'_{kj}(C_j - C_k))$$

$$-V_k K_k c_k + W_k \pm \Sigma K; \; K=1,2......n \qquad \text{(T-14)}$$

where all terms have been defined previously and the summation extends over all j segments bordering on segment k. This equation also results from a formal finite-difference approximation to Equation T-13 with a variable weight given to the advective term. If all terms involving the dependent variable c_k are grouped on the left hand side, one obtains

$$a_k C_k + \Sigma a_{kj} C_j = W_k \pm \Sigma K$$

where

$$A_{kk} = \Sigma(A_{kj} \alpha_{kj} + E'_{kj}) + V_k K_k$$

$$A_{kj} = Q_{kj} \epsilon_{kj} - E'_{kj} \qquad \text{(T-15)}$$

The flow convention is positive leaving the section. Note that

$$Q_{jk} \alpha_{jk} = Q_{kj} \epsilon_{kj}$$

and

$$Q_{jk} \epsilon_{jk} = Q_{kj} \alpha_{kj}$$

For sections on a boundary where the flow between the boundary and the section is designated Q_{kk} (positive leaving the section),

$$A_{kk} = \Sigma_j (Q_{kj} K_j + E'_{kj}) \quad V_k K_k + Q_{kk} \alpha_{kk} + E'_{kk} \qquad \text{(T-16)}$$

and the forcing function is

$$W_k = W_k + (E'_{kk} - Q_{kk} \epsilon_{kk}) C_B \qquad \text{(T-17)}$$

where C_B is the boundary concentration. For Q_{kk} entering the section from the boundary (negative),

$$A_{kk} = \Sigma_j (Q_{kj} \alpha_{kj} + E'_{kj}) + V_k K_k + Q_{kk} \epsilon_{kk} + E'_{kk} \qquad \text{(T-18)}$$

and

$$W_k = W_k + (E'_{kk} - Q_{kk} \alpha_{kk}) C_B \qquad \text{(T-19)}$$

The n equation with suitable incorporation of boundary conditions can be represented in matrix form as

$$\begin{bmatrix} A_{11} & A_{12} & \cdots\cdots & A_{1n} \\ A_{21} & A_{22} & \cdots\cdots & A_{2n} \\ \cdot & \cdot & \cdots\cdots & \cdot \\ \cdot & \cdot & \cdots\cdots & \cdot \\ \cdot & \cdot & \cdots\cdots & \cdot \\ A_{n1} & A_{n2} & \cdots\cdots & A_{nn} \end{bmatrix} \times \begin{bmatrix} C_1 \\ C_2 \\ \cdot \\ \cdot \\ \cdot \\ C_n \end{bmatrix} = \begin{bmatrix} W_1 \\ W_2 \\ \cdot \\ \cdot \\ \cdot \\ W_n \end{bmatrix}$$

or

$$A \; (c) = (W)$$

where (A) is an n x n matrix of known coefficients that depends on the system parameters. For most applications, a relatively large number of the elements of (A) are zero. The multi-dimensional matrix can be compared to the tri-diagonal form for one-dimensional estuaries.

As indicated for both the one- and two-dimensional estuarine analysis, the steady-state solution of a natural water system response to a specific discharge(s) ultimately reduces to the solution of n simultaneous equations each of which represents the mass transport into and out of each respective segment. The actual solution technique may involve a simultaneous equation solution procedure, as in this case, or any number of other matrix inversion routines. The advantage of the matrix inversion routine, however, lies in the fact that a reference matrix (Eq. T-6) may be formulated for subsequent analyses on the water system without the requirement of further computer runs.

The results which are obtained for specific water quality constituents from this approach represent tidally averaged concentrations which can be expected after the system has reached a condition of dynamic(steady-state) equilibrium. The range of fluctuations about the projected values obtained by this technique thus depend largely upon the nature of the existing tidal hydraulics and related phenomena.

IV. Model Application to the Raritan Bay System

Any natural water system may be viewed as a unique mathematical system consisting of a specific combination or array of complex interacting subsystems, each of which exhibits singular geometric, hydrodynamic and kinetic properties. The physical response of the system to a particular pollutant discharge may be described by a set of differential equations which represent the individual properties of each subsystem and its effect on adjoining segments.

The purpose of a mathematical model of a natural water system is thus to reproduce observed natural phenomena of particular significance through the application of mathematical techniques on a segment by segment basis.

In the finite difference approach used in the analysis of the Raritan Bay System the initial procedure consisted of the development of an adequate segmentation scheme based upon known wastewater input locations, geometric, hydraulic and circulation factors. The Raritan System, like many natural estuaries, may be segmented into an arbitrary number of discrete segments in which there are no steep pollutant concentration gradients and in which the pollutant levels may be considered uniform, i.e., the segment are assumed to approximate completely mixed water volumes. Inherent in this approach is the added assumption of vertical homogeneity or the absence of any vertical stratification of the water quality constituent being modeled.

The general counterclockwise circulation patterns existing within the Raritan Bay System and discussed in the Hydrology section of this report form the basis for the resultant Raritan Bay System segmentation (Fig. 3.). *A priori* knowledge and quantification of the specific flow routing due to the Raritan and Hudson River influences was provided largely through past research performed by the Woods Hole Oceanographic Institute (WHOI) (1949), Ketchum (1951), Jeffries (1962), and through reference to U.S.G.S. Current Charts (1956). Small scale adjustments to the 50 segment scheme were subsequently based upon known physical data concerning specific wastewater inputs, shoal and channel locations and probable dissolved oxygen (D.O.) sources and sinks. The final grid pattern generally consists of smaller segments near the western end of the Bay where the major waste inputs are located and where water quality conditions are usually more critical. The segmentation thus allows greater definition of specific pollutant distributions in this area of concern and precludes the possibility of excess concentration gradients within individual sections. Segments located west of the Raritan Bay-Lower Bay boundary line at Point Comfort are generally smaller than 1.5 square miles in surface area while in the Lower Bay and Sandy Hook Bay the segmentation consists of larger sections as a result of the smaller observed pollutant gradients, the lesser definition of specific flow paths, and the absence of any significant point waste sources.

The primary mass(pollutant) transport mechanisms within the Raritan

Bay System are the freshwater flushings due to the various natural and artificial water sources and the dispersive mixing provided by the semi-diurnal tidal oscillations.

The dispersive transports utilized in the model verification and subsequent water quality projections are represented by appropriate coefficients which have been assigned to each of the model interfaces as indicated in Figure 4. In many natural estuarine systems, lateral dispersion, as indicated by these coefficients, are usually on the order of 1/2 to 1/10 the longitudinal coefficients. However, in the Raritan Bay System these parameters were found to be generally of the same order due largely to the two-dimensional nature of the large scale circulation patterns and the effects of the many smaller eddy formations. Initial estimates of these coefficients were provided by tidal current charts and the empirical Four-Thirds Law relating this parameter to peak tidal velocities. More accurate estimates of this dispersion coefficients were subsequently provided by utilization of the salinity profiles observed throughout the Bay as described in later sections of this report.

Although of much lesser significance than the dispersion transport in Raritan Bay, the freshwater(advective) transport was also considered in the study. River and sewage treatment plant flows were routed from point of entry to ocean boundaries along routes indicated by general circulation patterns mentioned in past field studies. Some consideration was given to the probability of advection along major shipping channels and deeper portions of the system, however, the primary excursion routes for the advective paths was assumed to be along preassigned circulatory channels and/or other direct routes to the ocean. Wastewater effluent flows were determined largely from Interstate Sanitation Commission(ISC) and STORET data while river flows were obtained from U.S. Geological Survey (U.S.G.S.) stations in the Raritan Basin, e.g., Raritan River at Kisco Dam, South River at Old Bridge, and on Lawrence Brook at Farrington Dam, and were extrapolated to the mouth of the Raritan River at Perth Amboy. The resultant flow-frequency graph at this location has been included for reference in Figure 5.

All physical data pertinent to the individual segments within the system, e.g., mean sea level (MSL) depths, section volumes, interfacial areas, characteristic lengths, etc., was obtained from U.S. Coast and Geodetic Survey Map No. 369-SC (New York Harbor, 1971).

Steady-State Model Verification

The major test for the validation of a particular model, its mathematical technique(s), the underlying assumptions, and the specific physical-hydraulic parameters employed consists of the verification or comparison of calculated water quality responses to actual observed data. Throughout the discussion of the model application to the Raritan System, it was assumed that the system parameters, e.g., dispersion coefficients, flow routing and quantification, etc., were known a priori values. Yet, in many cases, the means to allow more precise specification of these parameters were not available. The order of magnitude of many of the system and input(waste load) parameters was known only through either past research, empirical correlations or independent analyses designed specifically for the determination of a particular unknown. Consequently, past survey data indicating average salinity profiles was utilized to more accurately define the specific dispersive properties of the Bay, while existing dissolved oxygen data allowed verification of the DO sources and sinks throughout the system.

Salinity Verification

In order to verify the transport mechanisms inherent in the model, a conservative(non-degradable) constituent is often traced from a known source location as it is advected and/or dispersed throughout the system. Tracer dyes, e.g., Rhodamine B, are often utilized for this purpose, however, in the absence of such artificial sources, salinity(or chloride) is the most common constituent traced. The basic assumption behind this selection is that the identical transport mechanisms will operate on discharged pollutants as on chlorides introduced to the system through ocean boundaries or known point sources.

The period selected for the chloride verification of the Raritan Bay System extended over the months of August and September for the ten(10) year interval from 1962 to 1972. Mean chloride data was obtained from the STORET system for all stations within the Bay at which more than 10 samples were available. The chloride data and pertinent standard deviations at each station are plotted for reference in Figure 7. It should be noted that, in general, the standard deviations shown are greater at stations in the lower Raritan River, Arthur Kill and lower Hudson area, where tidal ranges are usually more severe and where advective(freshwater) effects have not yet been dampened.

The major chloride sources in the Bay range from the 175,000 #/day discharged by MCSA to the relatively insignificant loads contributed by the Highlands and Atlantic Highlands facilities. Data pertinent to all other point chloride sources was obtained from STORET surveys and has been included in the aforementioned Table 1.

In order to compute the chloride concentrations within the model, the chlorinity was specified for all boundaries within the system. Along the coastal traverse, these values range from 15.20% at segment 4 to 15.65% at segment 3. The chloride concentrations established for the Raritan River and Arthur Kill boundaries were 13.00% and 13.70% respectively. All chloride boundary condition concentrations were based upon observed 10-year mean summer values as were the freshwater(advective) input flows.

The major freshwater source to the western end of the Bay - the Raritan River flow - was determined from U.S.G.S. records over the survey interval. The 500 cfs used approximates this 10-year mean August-September flow. The subsequent flow routing was established on the basis of the aforementioned criteria and has been indicated on Figure 6.

The calculated 10-year mean chloride profiles have been superimposed on the August-September chloride values observed over the same time period to allow comparison(Fig. 7). "Goodness of fit" between the observed and calculated chloride values was evaluated by the application of two(2) statistical analysis routines: 1) a Student's 't' test was performed at each station to determine the 95% confidence limits around observed values and 2) the mean standard deviation of all observed values was obtained from the STORET system. The calculated chloride contours (isoclors) fell well within the range of predictions permissible under each of these statistical analyses.

Dissolved Oxygen Verification

Past water quality surveys in the Raritan Bay System have indicated specific regions wherein present water quality standards, as mandated by the New Jersey State TW-1 classification and the Interstate Sanitation Commission (ISC) 'A' classification, are being contravened. Most notably, the minimum required DO levels of 4.0 mg/l (New Jersey State) and 5.0 mg/l (ISC) are both being contravened in the western end of the Bay in the vicinity of the MCSA discharge, and also in the Arthur Kill and the tidal stretch of the Raritan River. As such, the DO analysis included in this report is limited largely to that portion of the Bay System which is located west of Point Comfort with the exception of the discussion of boundary condition influences.

The instream DO levels in the Bay area are an important index of water quality conditions in that certain minimum concentrations of this constituent are necessary for the survival of many aquatic organisms. The major sources and sinks of DO in the Raritan Bay System are carbonaceous and nitrogenous oxygen demands, benthic uptake from organic sediments, photosynthetic production and respiration and atmospheric rearation. General background on each of these parameters and their particular significance and quantification in the Raritan Bay System are discussed below.

Biochemical Oxygen Demand:

When wastewater is discharged into a stream or estuary, the decomposable organic matter becomes food supply for the living organisms in the aquatic environment. The biochemical oxygen demand (BOD) of an effluent is a measure of the oxygen consumed when specific microorganisms utilize this organic matter as food and convert the more complex compounds into simpler products.

There are two stages of BOD; the first being due to carbonaceous BOD and the second due to nitrogenous oxidation demand(NOD). The rate at which oxygen is utilized during both of these processes is dependent upon instream temperatures, dissolved oxygen levels, and ph among other parameters. Both decomposition kinetics are aerobic, although different individual species are responsible for each.

The 5-day BOD concentrations for the three(3) major discharges in the Raritan Bay System - MCSA, Perth Amboy and Oakwood Beach - were obtained from the STORET system for the DO verification period of July 12-22, 1971. These values were 400, 290, and 35 mg/l which represent 240,000, 17,300 and 3800 #/day BOD_5, respectively. The corresponding NOD contributions due to these three(3) major discharges over this interval as determined from the STORET data were 44,800, 4500 and 5350 #/day, respectively. More detailed information concerning these and all other significant discharges to the Raritan Bay System has been included for reference in Table 1. The BOD decay(removal) rate for all segments in the Bay was assumed to be 0.25 day^{-1} at 20°C. This rate, however, was altered within the program due to varying temperatures recorded throughout the Bay over the verification period. The relationship utilized

$$K_R = 0.25 \times (1.04)^{T-20}$$

where T is the temperature (°C) which results in decay rates (K_R) ranging from 0.255 day^{-1} to 0.288 day^{-1}. Implicit in the model analysis was the assumption that the NOD decay rate was identical to the carbonaceous rates and thus both deoxygenation processes occurred simultaneously.

The temperatures utilized for the DO verification were those recorded by the July 12-22, 1971 ISC survey, however, 10-year mean August-September values were applied for the subsequent DO projections for the design year 2020.

Photosynthetic Sources:

It was observed that during the July, 1971 DO verification survey supersaturation of dissolved oxygen occurred in certain areas of the Bay, especially in the Sandy Hook Bay area where average DO values were on the order of 9.44 mg/l and 9.16 mg/l at two(2) particular stations (Fig. 9). Specific analyses to determine the extent of this phenomena (FWPCA, 1969) at two(2) stations near the head of the Bay recorded a net O_2 production of approximately 2.0 mg/l/day in the upper 9 feet of water. To account for this phenomena, an average dissolved oxygen source was added to various segments in the western end of the Bay in the Conaskonk Point-Point Comfort vicinity. Net values of 1.0 mg/l/day in Keansburg Harbor(section 48), 0.9 mg/l/day in Keyport Harbor(sections 27 and 28) and 0.10 mg/l/day in the deeper central area(sections 18, 19, 20, 23, and 47) were incorporated into the model to account for photosynthetic effects. No photosynthetic sources were included for the extreme western Bay area due to the suppressant effects of the generally more turbid water, probable toxicity from Arthur Kill discharges and the greater observed zoo-plankton respiratory rates which would tend to offset any net O_2 production.

Benthal Oxygen Demands:

Sludge deposits are present in the western end of the Bay especially in adjacent embayments and are due largely to the relatively high levels suspended matter discharged by the treatment facilities located in this region. Although there are no estimates of the magnitude of the oxygen demand represented by these benthal deposits, it is possible that a significant portion of this uptake has been suppressed by toxic substances originating from the Arthur Kill and subsequently settling in the more shallow and quiescient areas of this inner Bay region. For the purpose of this analysis the benthic sinks were assumed to be zero in all segments of the inner Bay region.

Atmospheric Rearation:

Aside from photosynthetic oxygen production, the only remaining oxygen source in the inner Bay area is due to atmospheric rearation. The rate of this rearation is directly proportional to the DO deficit, the instream temperature and the turbulence of the water and is inversely proportional to the depth of the water body. The value of the rearation coefficient(K_A) for Raritan Bay ranges from 0.3 day^{-1} near the mouth of the Raritan River to 0.1 day^{-1} at the Raritan Bay-Lower Bay boundary at Point Comfort (Hydroscience, 1968). Accordingly, the rearation coefficient was set at 0.20 day^{-1} for all segments within the inner Bay area. The temperature correction applied to this coefficient by means of the equation

$$K_A = 0.20 \times 1.025^{(T-20)}$$

where T is the temperature (°C) results in rearation rates ranging from 0.208 day^{-1} to 0.212 day^{-1} throughout the area of concern.

Verification Procedure:

The period chosen for verification of the calculated dissolved oxygen profiles was July 12-22, 1971. The joint ISC - New Jersey State survey undertaken over this period provided the dissolved oxygen data presented in Figure 9. Fifteen(15) sampling stations were selected for surveillance on eight(8) days within the 11 day period. Two(2) samples were collected daily at stations 1 through 8 and three(3) daily samples were collected at stations 9 through 15, thereby providing sixteen(16) and twenty-four(24) samples at each of these respective sets of sample stations.

The BOD and DO deficit boundary conditions set for the July, 1971 survey period were based on 10-year August-September mean water quality conditions observed at stations closest to each specific boundary and are as follows:

Segment	BOD (mg/l)	DO deficit (mg/l)
1	2.28	3.20
7	2.26	4.75
50	2.26	3.90

The BOD and DO deficit concentrations at the coastal interfaces between Sandy Hook and Norton Point and at the Shrewsbury-Navesink interface were assumed to be zero.

The Raritan River flow of 250 cfs over the survey period was determined from U.S.G.S. data and extrapolated on a flow per unit drainage area basis to the mouth of the Raritan at Perth Amboy in the same procedure utilized in the preparation of Figure 5. The subsequent flow routing represented in Figure 8. was established largely on the basis of past hydrologic studies discussed in earlier sections of this report with additional reference to STORET records for pertinent treatment plant flows at that particular time.

The distribution of dissolved oxygen throughout the critical inner Bay area (west of Point Comfort) was calculated for the July, 1971 survey period on the basis of the aforementioned assumptions and by utilizing the parameters discussed. The individual DO profiles have been plotted along with the observed DO values from the joint survey to permit comparison (Fig. 10).

Application of the Students 't' 95% confidence limits and standard deviation comparison tests, as was performed on the calculated chloride profiles, indicated that the agreement between the calculated and observed isopleths represents adequate simulation of the dissolved oxygen kinetics and distribution throughout the western Bay area.

Effect of Individual Waste Sources

A number of additional DO analyses were performed to assess the effect of individual waste sources on instream DO distributions and thereby allow more adequate evaluation of future abatement proposals. The particular analyses undertaken were based upon the July, 1971 survey period and concerned the individual DO deficit response due to each of the following specific waste inputs:

a. Middlesex County Sewerage Authority alone
b. Boundary effects.

The DO deficits resulting from each of these particular waste sources during the July, 1971 survey have been plotted for reference on Figures 11, and 12. In both cases, the 250 cfs Raritan River flow routing (Fig. 8) and background photosynthetic effects were assumed constant.

V. Effect of Alternate Abatement Measures

Based upon the hydrodynamic characteristics of the Bay which were substantiated by the salinity verification and the dissolved oxygen kinetic parameters which were provided by the DO verification, it is now possible to determine the effects of any number of alternate abatement proposals, including outfall relocation, higher degrees of treatment and multiple dischrge points. The specific alternatives considered were all evaluated on the basis of year 2020 wastewater flows and the estimated 140 cfs Raritan River average daily flow which is exceeded 95% of the time (Fig. 5). All other parameters, e.g., benthal demand, photosynthetic production, etc, were assumed to remain constant, however, the flow routing was adjusted accordingly for each particular analysis.

MCSA Discharge at Existing Outfall Site

The estimated wastewater discharge from the MCSA facility utilized in the 2020 analysis was 140 mgd(372 cfs) which represents, after the proposed UNOX secondary treatment, an ultimate oxygen demand (UOD) equal to 350,000 #/day. This estimate is based upon an average effluent BOD5 of 50 mg/l and ammonia(NH3) concentration of 20 mg/l as indicated in the UNOX pilot plant operating data. Likewise, the Oakwood Beach, S.I. facility will contribute a UOD equal to 34,000 #/day based upon a design capacity of 40 mgd and effluent BOD_5 and NH_3 concentrations of 35 and 11 mg/l, respectively. All other existing point waste sources with the exception of the Oakwood Beach discharge are assumed to be serviced by either MCSA or by the Bayshore Regional Outfall Authority and, as such, are not included in the analysis. Future boundary conditions for BOD_5 and DO deficit are identical to those utilized in the DO verification analysis for the summer of 1971. The flow routing established for the Raritan River drought flow of 140 cfs which is used for the analysis is indicated in Figure 13. Reference to the anticipated DO distribution for the inner Bay area (Fig. 14) indicates that the 4.0 mg/l DO criteria (NJS) will be contravened in the extreme western sector of the Bay and in both the lower Raritan River and the Arthur Kill. The larger area wherein contravention of the 5.0 mg/l criteria (ISC) can be expected extends from the 4.0 mg/l isopleth to a point approximately 1 mile east of the present discharge site. These contraventions may be even more severe if the boundary conditions at the Raritan and Arthur Kill interfaces worsen, if benthic sinks begin to exert a more significant deficit due to the abatement of possible toxic suppressants from the Arthur Kill discharges, or if the net photosynthetic oxygen production in certain areas of the Bay is either reduced or eliminated.

MCSA Discharge off Keyport Harbor

The specific wastewater discharges and system parameters utilized in the analysis of the relocation of the MCSA discharge to segment 46 (at the mouth of Keyport Harbor) are identical to those employed in the previous analysis for discharge at the present outfall site. The flow routing, however, was altered slightly to reflect the change in outfall location and the resultant loss of advective transport in the western end of the Bay. The calculated DO profiles (Fig. 15) indicate a general abatement of the DO contraventions within the inner Bay area when compared to the previous MCSA discharge analysis at the existing site. The results indicate a minimum DO of 3.26 mg/l in the Arthur Kill as opposed to 3.01 mg/l in the same segment for the present site analysis. Both analyses indicate contravention of the 4.0 mg/l and 5.0 mg/l minimum DO criteria will occur, however, relocation of the outfall to section 46 will allow greater dispersion of the MCSA discharge throughout the Bay and will thereby lessen the severity of its impact on the oxygen resources in any of the more critical areas within the System.

The particular outfall relocation analyses discussed above indicate that the major advantage of the existing outfall site lies in the magnitude of the tidal currents affecting the effluent plume which have been observed to reach a peak velocity of 1.1 knots(1.96 fps). However, the major disadvantages of the present discharge site consist of the following items, which tend to significantly reduce the natural assimilative capacity in this portion of the Bay:

a. the generally shallow depths (often less than 10 feet) which inhibit initial plume dilution

b. the reduction of large scale effluent dispersion by the proximity of the surrounding shorelines

c. The tendency for eddy and tidal effects to disperse portions of the plume onto nearby shores and up the Raritan Estuary and Arthur Kill where there is minimal assimilative capacity due to natural physical constrictions and poor flushing characteristics

d. the potential inhibition to flushing due to the effects of the general circulation patterns exhibited further out in the bay

e. the presence existing background oxygen demands exerted by neighboring waste discharges, boundary condition effects and potential benthic uptakes

In summary, the analysis presented adequately simulates present water quality conditions and also indicates the relatively disadvantageous nature of the western end of the Bay area for consideration as an ultimate discharge site. The investigation into alternate outfall sites generally demonstrates the decreasing impact of the MCSA discharge with relocation into the central Bay area where the effluent plume will be more effectively dispersed by the predominant circulation patterns which occur in this area.

VI. Conclusions and Recommendations

Based on the results of this preliminary two-dimensional analysis the following conclusion concerning the Raritan Bay System and the Middlesex County Sewerage Authority (MCSA) discharge are presented:

1. The Raritan Bay System is a tidal waterway governed primarily by tidal oscillations, dispersion mechanisms and the hydrodynamic influences of the freshwater sources provided by the Raritan River and Hudson River Basins.

2. Existing dissolved oxygen conditions in the inner Bay area contravene the established New Jersey State (4.0 mg/l) and Interstate Sanitation Commission (5.0 mg/l) criteria during summer months.

3. The existing MCSA discharge is the most influential point waste source in the Raritan Bay System and is largely responsible for the DO contraventions exhibited in the inner Bay region.

4. Review of past hydrodynamic studies indicates that large counterclockwise circulation pattern(s) exist in the Bay System which tend to entrap pollutants within certain areas of the System; the only places where non-tidal drifts clearly remove pollution from the Raritan Bay System are around the tip of Sandy Hook and in the main New York (Ambrose) Channel.

5. An adequate mathematical model can be developed to simulate present water quality conditions and to allow evaluation of alternate pollution abatement measures; through the use of such a model the effect of individual waste sources can be isolated to aid in the assessment of their significance and abatement; the mathematical model developed in this analysis adequately represents the kinetics and distribution of instream DO concentrations resulting from wastewater discharges from all known point sources to the Raritan Bay System.

6. The analysis indicates that discharge of the secondary effluent from the MCSA treatment facility at the present outfall site will result in contravention of both the New Jersey State (TW-1) and ISC (Class 'A') water quality standards under the estimated ultimate oxygen demand loading of 350,000 #/day for the year 2020.

7. The analysis further demonstrates that, as the MCSA discharge location is moved out into the Bay, the relocation generally provides more effective dilution of the wastewater effluent, more adequate utilization of the natural assimilative capacity

of the Bay and results in less severe water quality conditions in the critical inner Bay region.

8. Assuming an estimated MCSA waste loading of 350,000 #/day for secondary treatment in the year 2020, relocation of the outfall to a site near the mouth of Keyport Harbor(segment 46) will result in marginal DO conditions in the inner Bay region with respect to the New Jersey State TW-1 criteria of 4.0 mg/l. The ISC standard of 5.0 mg/l will be contravened throughout the western end of the Bay. The analysis assumes no improvement in boundary conditions, however, all other waste loadings except the Oakwood Beach effluent are excluded from the analysis.

9. Under the estimated year 2020 loadings, relocation of the MCSA outfall to the central Bay region(segment 19) will provide general compliance with the New Jersey State minimum DO requirement(4.0 mg/l); however, compliance with the ISC Class 'A' standard of 5.0 mg/l will be contingent largely upon the improvement of boundary water quality conditions in the lower Raritan River and Arthur Kill.

10. For the estimated year 2020 loadings, the analysis indicates that relocation of the MCSA outfall site beyond Conaskonk Point is required to meet the New Jersey State (TW-1) DO standard; the required outfall length may be minimized by utilization of the deeper waters in the central Bay area, possibly through an interstate agreement with New York State; it is recommended, however, that a sophisticated study program and related field survey be undertaken to more adequately define the hydrodynamics of this area and the impact of alternate outfall siting in this region prior to final site selection.

The aforementioned conclusions are tentative in nature, however, adequate simulation of the Raritan Bay System has been accomplished through this analysis. The results obtained can be utilized to investigate and subsequently quantify the impact of wastewater discharges on water quality conditions in the Bay. Throughout the course of the analysis a number of items were noted which deserve further investigation in possible future studies. These areas of concern are referenced for future consideration as follows:

1. Specific studies should be initiated to permit evaluation of such alternate abatement measures for the MCSA discharge as:

    a. outfall relocation into waters along the south shore of the Raritan Bay System.

    b. outfall relocation into the deeper central Bay region.

    c. multiple discharge sites along the central axis of the Bay System.

d. advanced waste treatment in conjunction with any of the above three (3) discharge alternatives.

2. More sophisticated analyses are desirable for the specific investigation of hydrodynamic phenomena in the Bay System, in general, and in the western end of the Bay, in particular.

3. Future studies should be initiated to more adequately define the significance of both benthal oxygen demand and photosynthetic production in the Bay during the critical summer-fall months.

4. An intensive 2-3 week study should be undertaken during late summer state-state conditions to provide a more adequate data base to allow more accurate salinity and DO verification over the entire Bay System.

5. Future analyses should be performed to investigate the impact of specific waste sources, boundary conditions and alternate abatement measures on the bacterial conditions in the Bay; specific consideration should be given to the potential for re-opening previously condemned bathing and shellfish harvest areas.

6. Sensitivity analyses should be undertaken to determine the significance of specific hydrodynamic and kinetic parameters, eg., freshwater flows and routing, rearation, BOD and coliform removal rates, dispersion coefficients, etc., with respect to resultant instream water quality responses.

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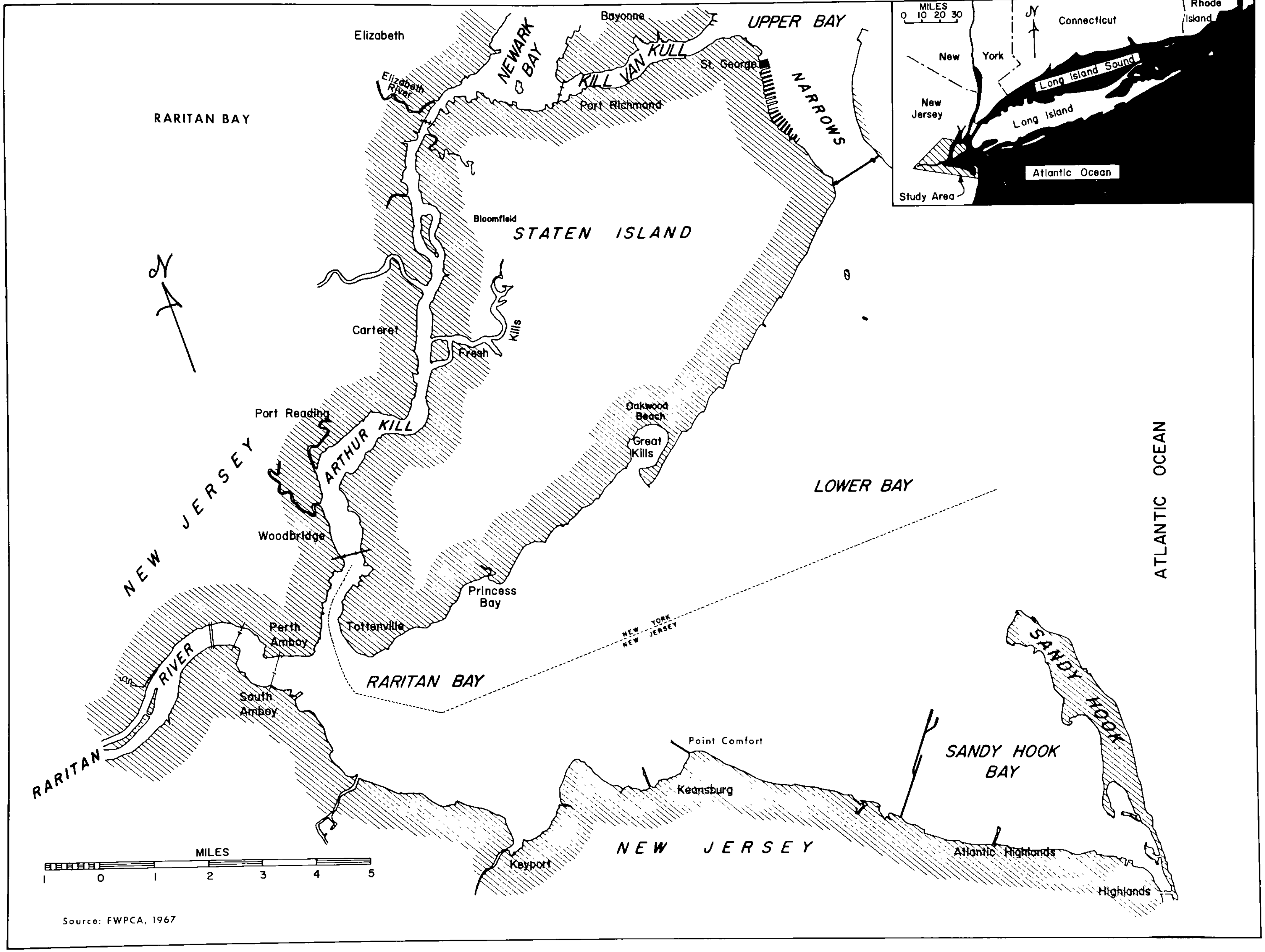
FIGURES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Bayonne
UPPER BAY
NEWARK BAY
KILL VAN KULL
St. George
Elizabeth River
Port Richmond
NARROWS
RARITAN BAY
Bloomfield
STATEN ISLAND
Kills
Carteret
Fresh
Port Reading
ARTHUR KILL
NEW JERSEY
Oakwood Beach
Great Kills
LOWER BAY
ATLANTIC OCEAN
Woodbridge
Princess Bay
Tottenville
Perth Amboy
NEW YORK
NEW JERSEY
RARITAN RIVER
RARITAN BAY
South Amboy
Point Comfort
SANDY HOOK BAY
SANDY HOOK
Keansburg
NEW JERSEY
Atlantic Highlands
Keyport
Highlands
MILES
1 0 1 2 3 4 5
Source: FWPCA, 1967
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0 10 20 30
Connecticut
Rhode Island
New York
Long Island Sound
New Jersey
Long Island
Atlantic Ocean
Study Area

Figure 1

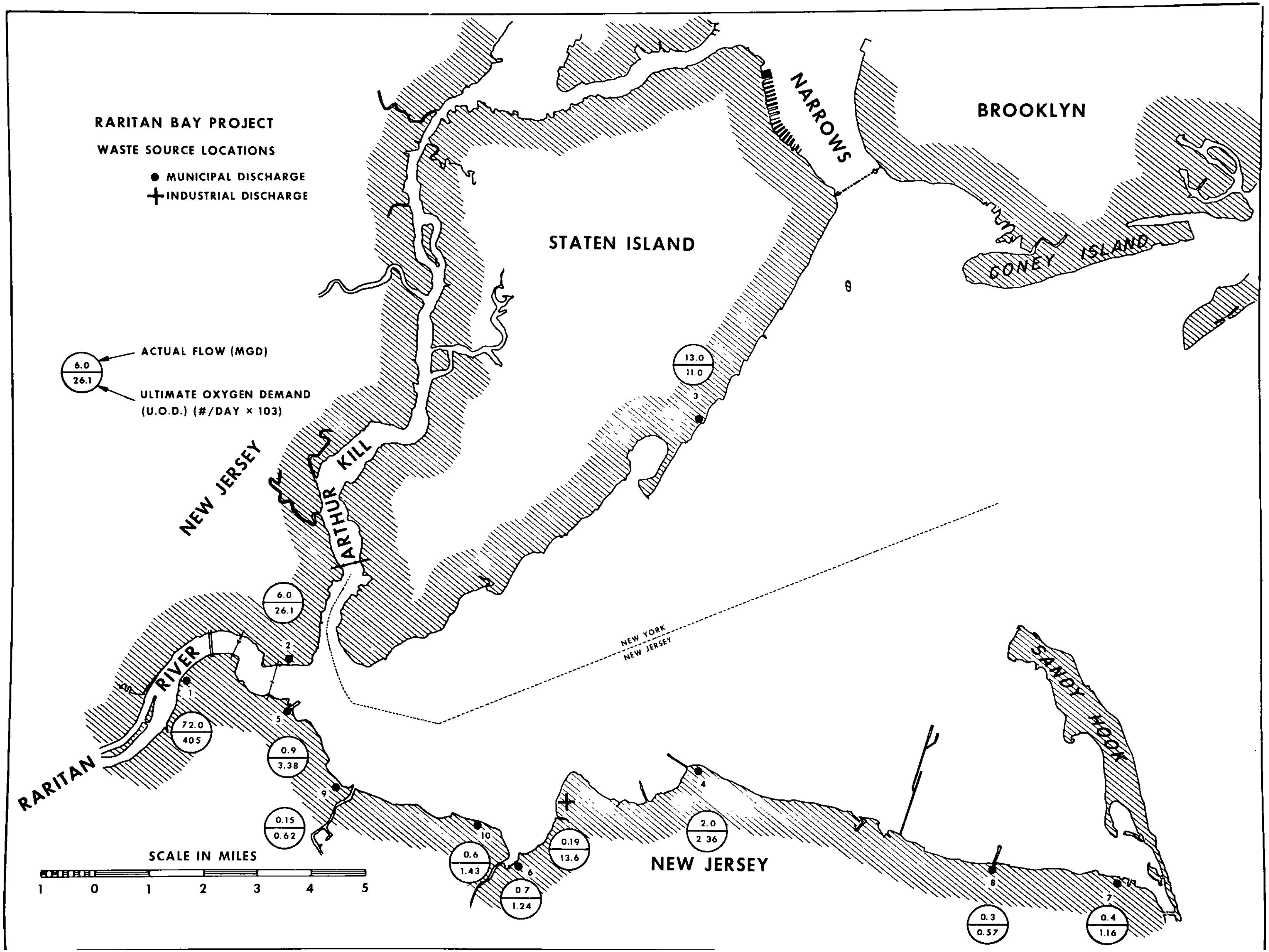

RARITAN BAY PROJECT
WASTE SOURCE LOCATIONS
● MUNICIPAL DISCHARGE
+ INDUSTRIAL DISCHARGE
6.0
26.1
ACTUAL FLOW (MGD)
ULTIMATE OXYGEN DEMAND (U.O.D.) (#/DAY × 103)
STATEN ISLAND
NARROWS
BROOKLYN
CONEY ISLAND
NEW JERSEY
ARTHUR KILL
RARITAN RIVER
SANDY HOOK
NEW YORK
NEW JERSEY
13.0
11.0
6.0
26.1
72.0
405
0.9
3.38
0.15
0.62
0.6
1.43
0 7
1.24
0.19
13.6
2.0
2 36
0.3
0.57
0.4
1.16
1
2
3
4
5
6
7
8
9
10
SCALE IN MILES
1 0 1 2 3 4 5

Figure 2

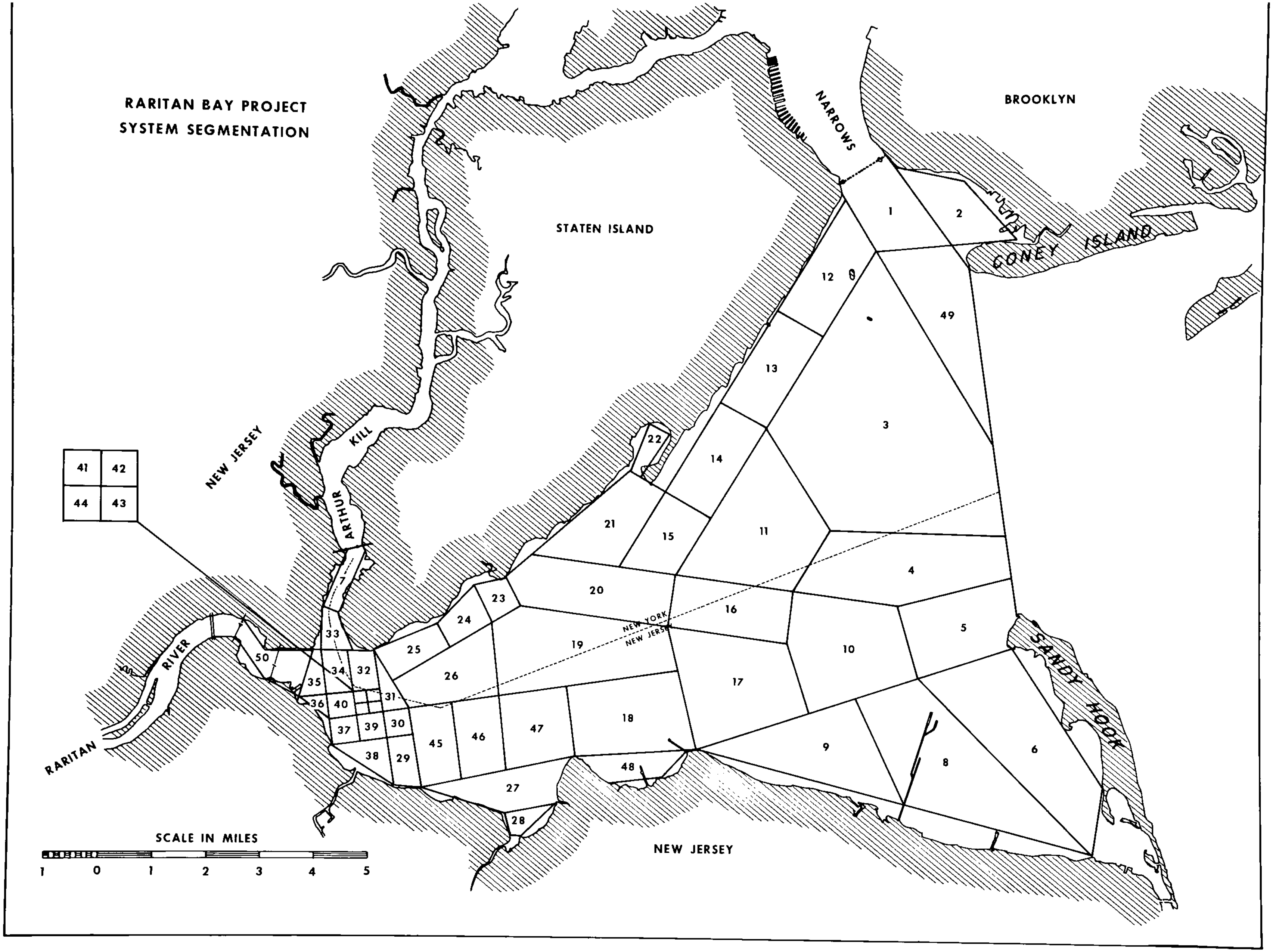

RARITAN BAY PROJECT
SYSTEM SEGMENTATION
STATEN ISLAND
BROOKLYN
NARROWS
CONEY ISLAND
NEW JERSEY
ARTHUR KILL
RARITAN RIVER
SANDY HOOK
NEW YORK
NEW JERSEY
NEW JERSEY
SCALE IN MILES
1 0 1 2 3 4 5
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50

Figure 3

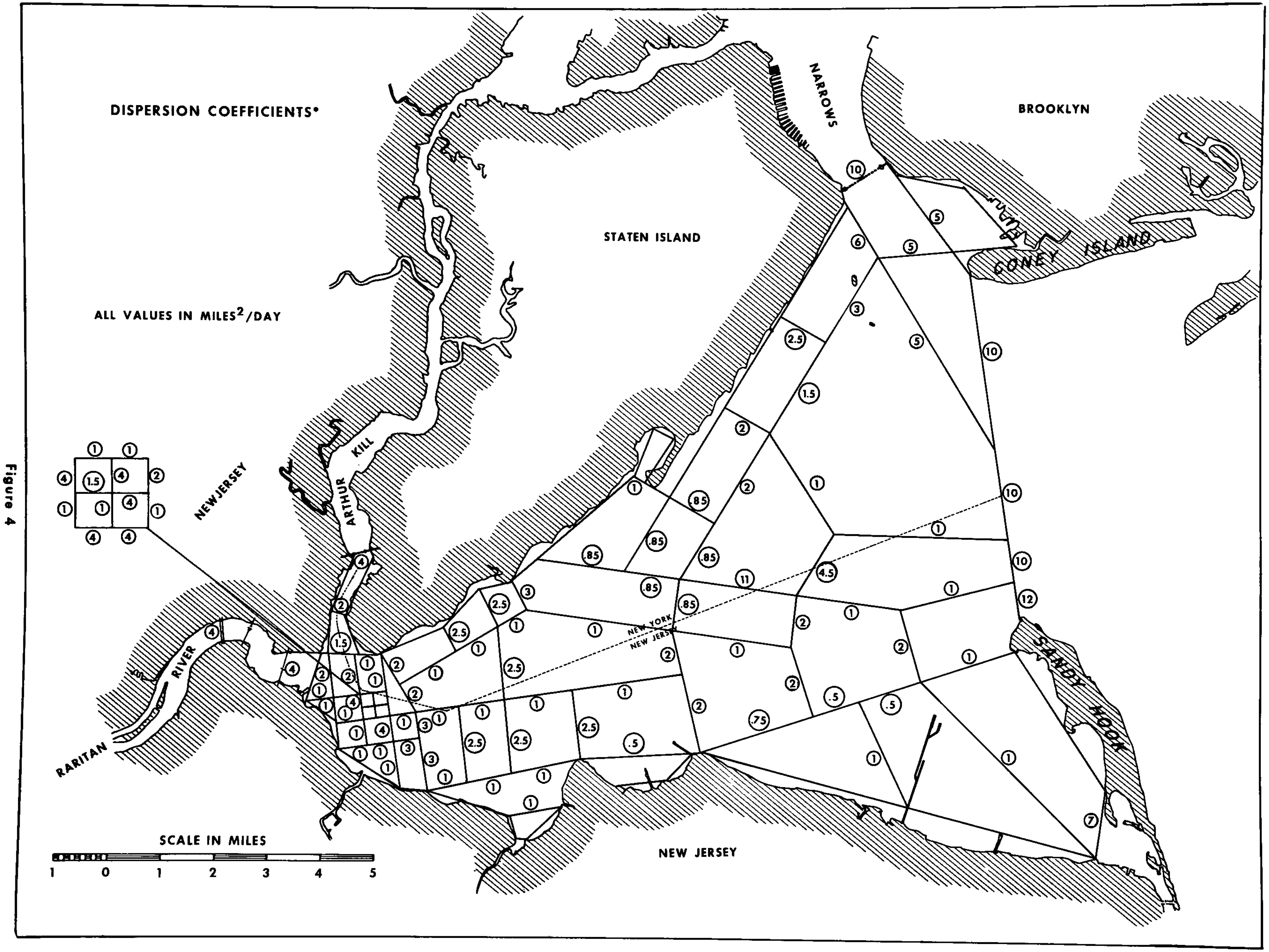

DISPERSION COEFFICIENTS*
ALL VALUES IN MILES²/DAY
STATEN ISLAND
NARROWS
BROOKLYN
CONEY ISLAND
NEWJERSEY
ARTHUR KILL
RARITAN RIVER
NEW YORK
NEW JERSEY
SANDY HOOK
NEW JERSEY
SCALE IN MILES
1 0 1 2 3 4 5

Figure 4

PROBABILITY PLOT OF EXTRAPOLATED DAILY DISCHARGE DATA

FOR RARITAN RIVER AT ENTRANCE TO RARITAN BAY

1904-08, 45-58, 60-63

DRAINAGE AREA 1072 SQUARE MILES

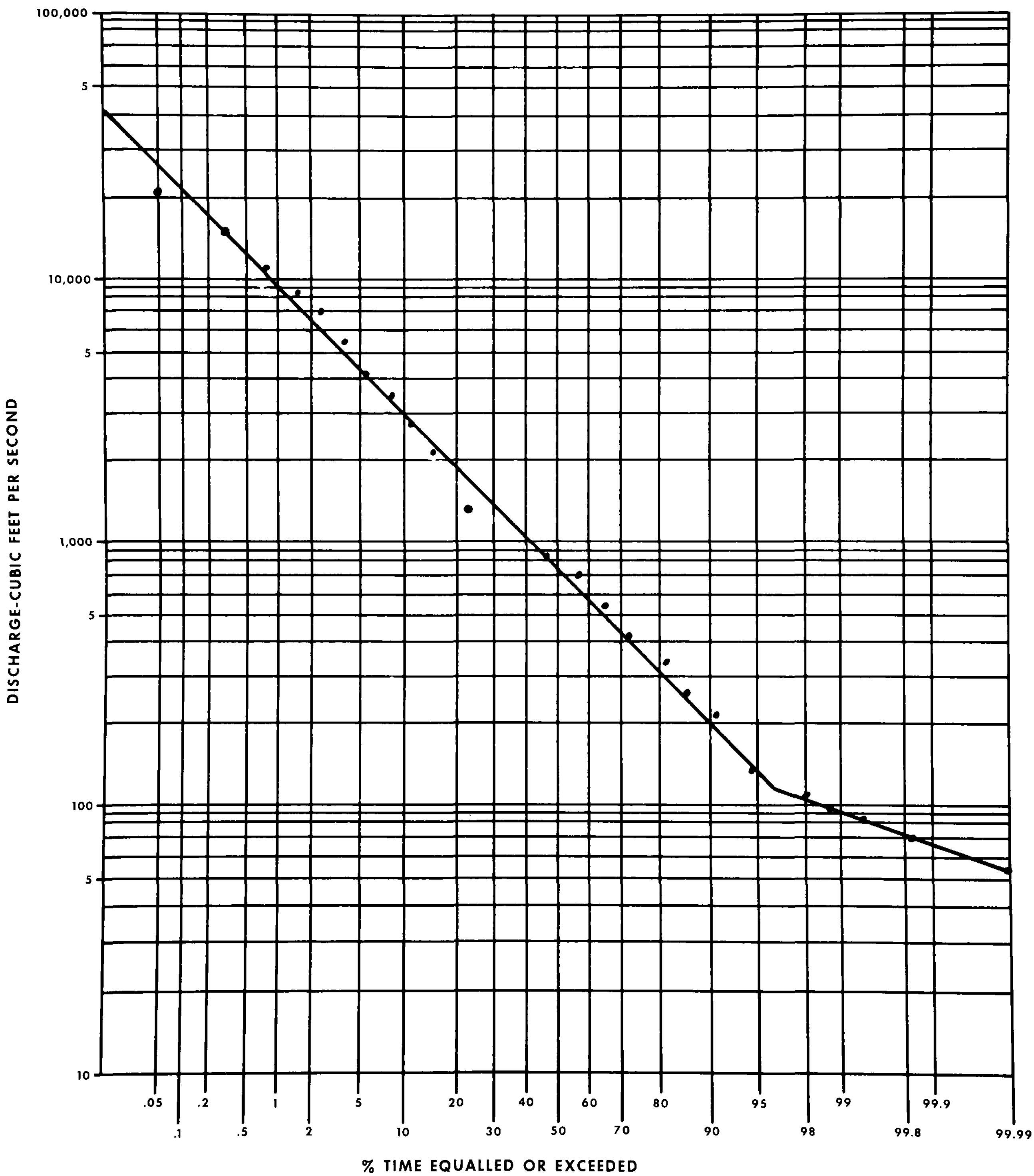


Figure 5

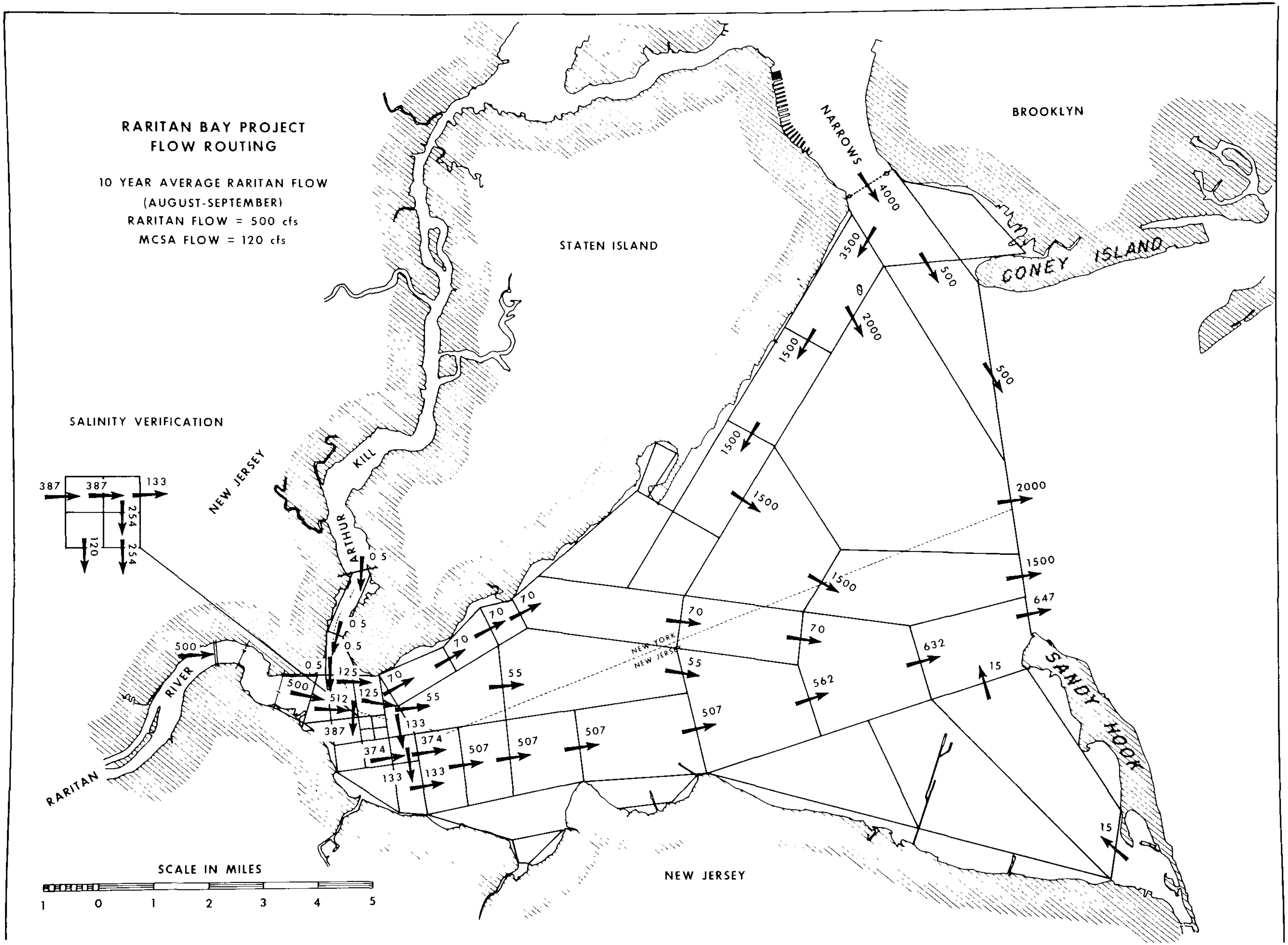

RARITAN BAY PROJECT
FLOW ROUTING
10 YEAR AVERAGE RARITAN FLOW
(AUGUST-SEPTEMBER)
RARITAN FLOW = 500 cfs
MCSA FLOW = 120 cfs
SALINITY VERIFICATION
387
387
133
254
120
254
STATEN ISLAND
BROOKLYN
NARROWS
CONEY ISLAND
NEW JERSEY
ARTHUR KILL
RARITAN RIVER
SANDY HOOK
NEW YORK
NEW JERSEY
4000
3500
500
2000
1500
500
1500
1500
2000
1500
1500
647
70
632
562
507
15
15
0.5
500
512
125
387
374
133
55
507
SCALE IN MILES
1 0 1 2 3 4 5

Figure 6

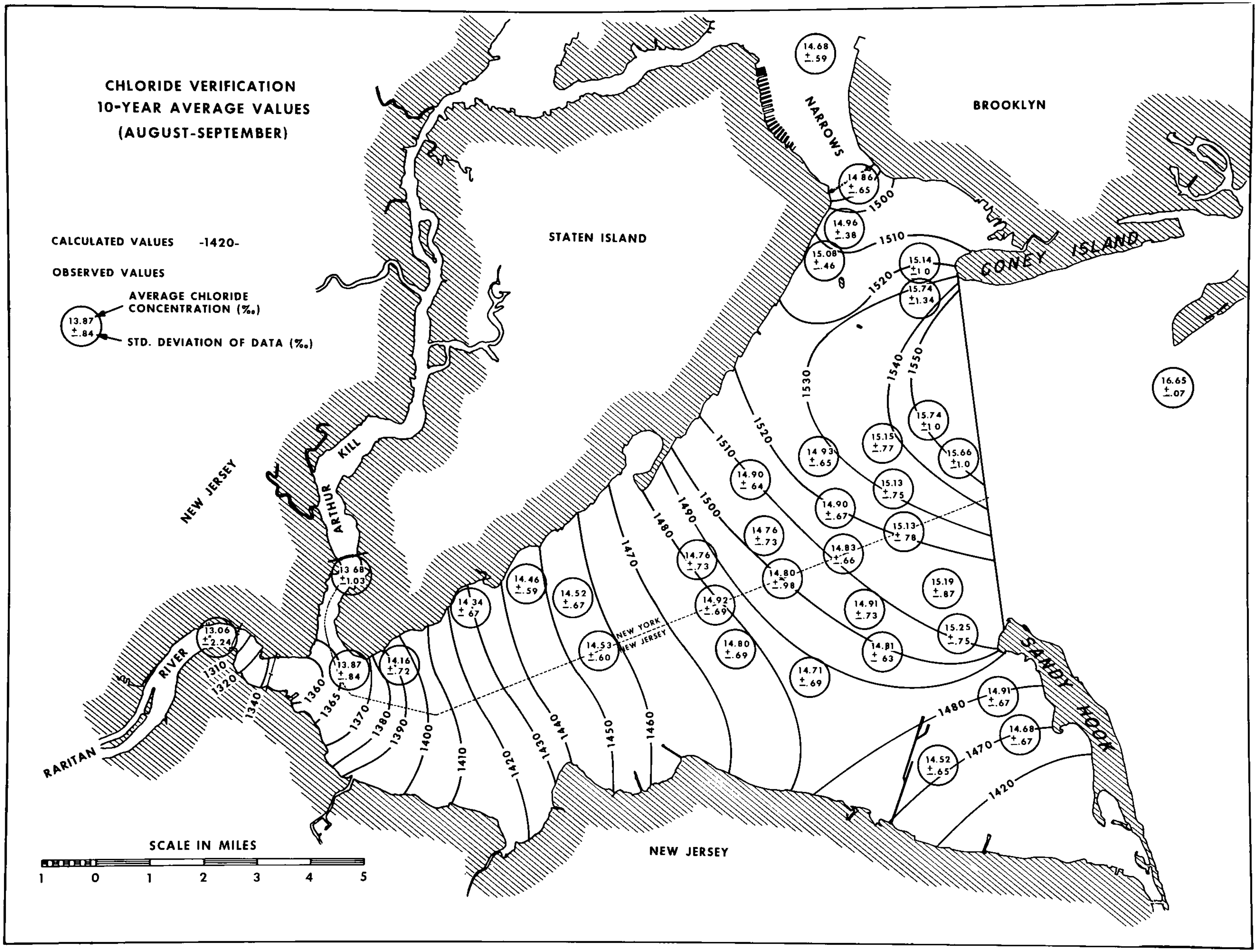

CHLORIDE VERIFICATION
10-YEAR AVERAGE VALUES
(AUGUST-SEPTEMBER)
CALCULATED VALUES -1420-
OBSERVED VALUES
AVERAGE CHLORIDE CONCENTRATION (‰)
STD. DEVIATION OF DATA (‰)
13.87 ±.84
STATEN ISLAND
BROOKLYN
NARROWS
CONEY ISLAND
SANDY HOOK
NEW JERSEY
ARTHUR KILL
RARITAN RIVER
NEW YORK
NEW JERSEY
NEW JERSEY
SCALE IN MILES
1 0 1 2 3 4 5

Figure 7

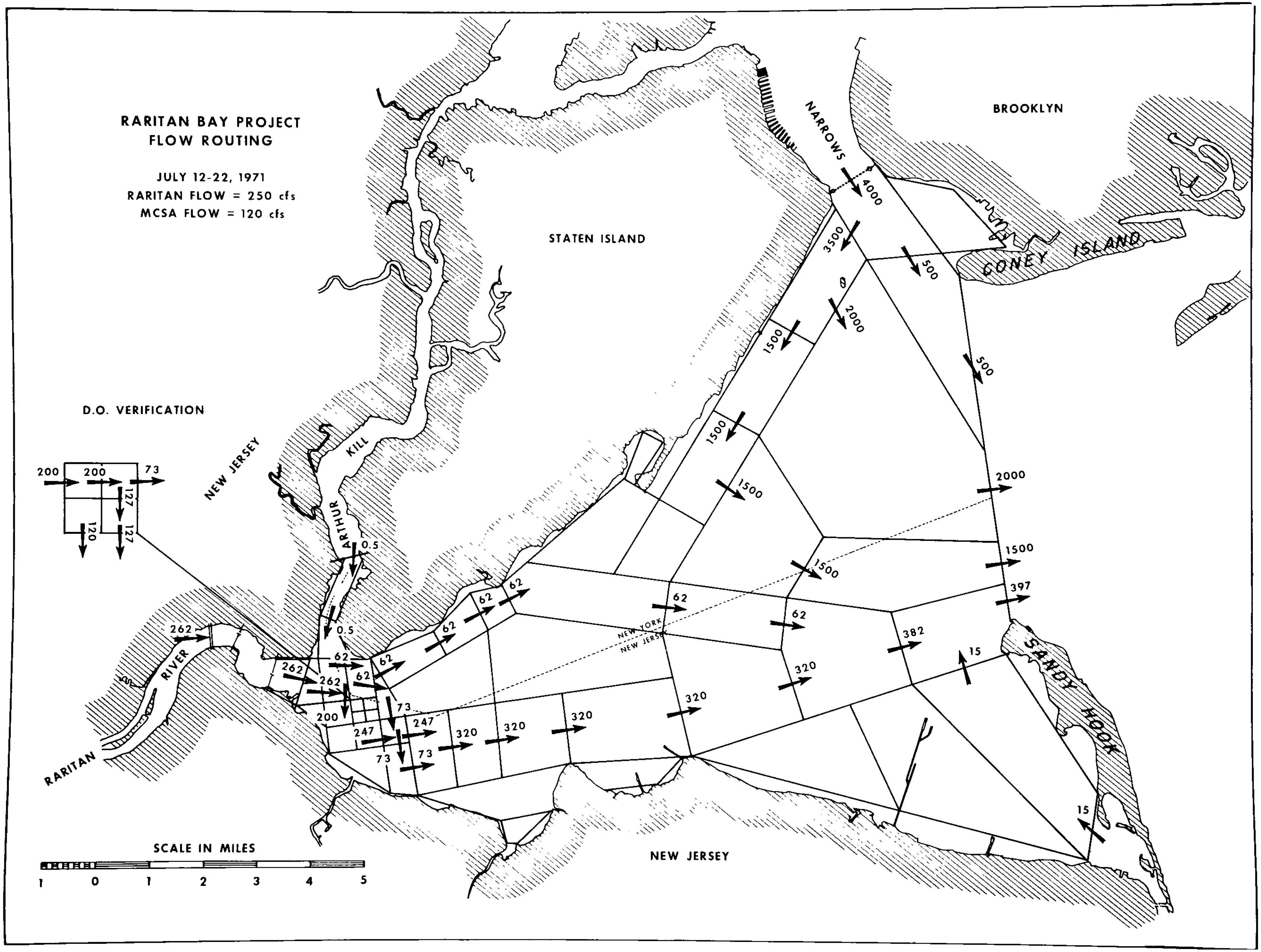

RARITAN BAY PROJECT
FLOW ROUTING
JULY 12-22, 1971
RARITAN FLOW = 250 cfs
MCSA FLOW = 120 cfs
STATEN ISLAND
BROOKLYN
NARROWS
CONEY ISLAND
SANDY HOOK
D.O. VERIFICATION
NEW JERSEY
ARTHUR KILL
RARITAN RIVER
NEW YORK
NEW JERSEY
NEW JERSEY
SCALE IN MILES
1 0 1 2 3 4 5

Figure 8

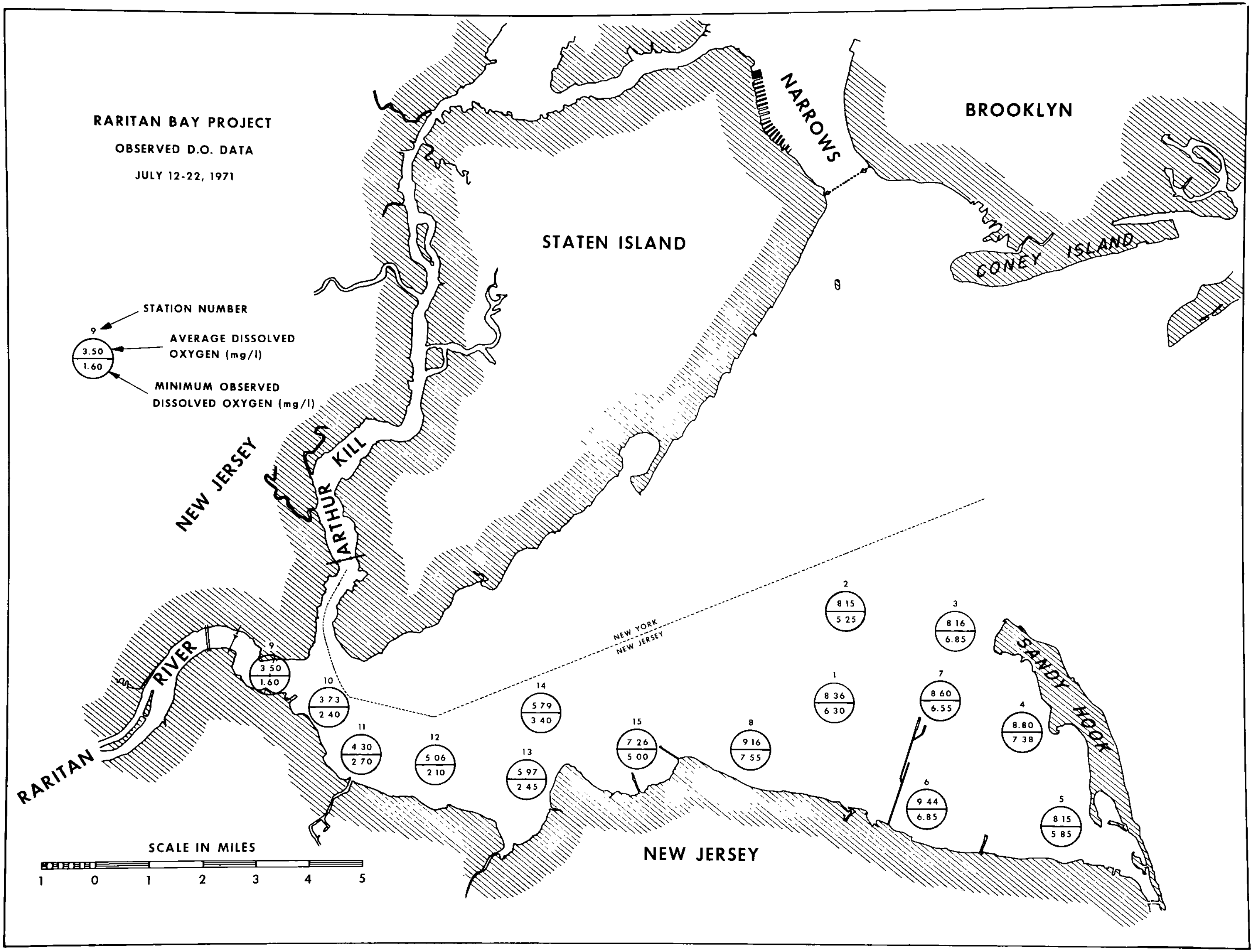

RARITAN BAY PROJECT
OBSERVED D.O. DATA
JULY 12-22, 1971
STATION NUMBER
AVERAGE DISSOLVED OXYGEN (mg/l)
MINIMUM OBSERVED DISSOLVED OXYGEN (mg/l)
9
3.50
1.60
STATEN ISLAND
BROOKLYN
NARROWS
CONEY ISLAND
NEW JERSEY
ARTHUR KILL
RARITAN RIVER
SANDY HOOK
NEW YORK
NEW JERSEY
NEW JERSEY
2
8 15
5 25
3
8 16
6.85
9
3 50
1.60
10
3 73
2 40
14
5 79
3 40
1
8 36
6 30
7
8 60
6.55
4
8.80
7 38
11
4 30
2 70
12
5 06
2 10
13
5 97
2 45
15
7 26
5 00
8
9 16
7 55
6
9 44
6.85
5
8 15
5 85
SCALE IN MILES
1 0 1 2 3 4 5

Figure 9

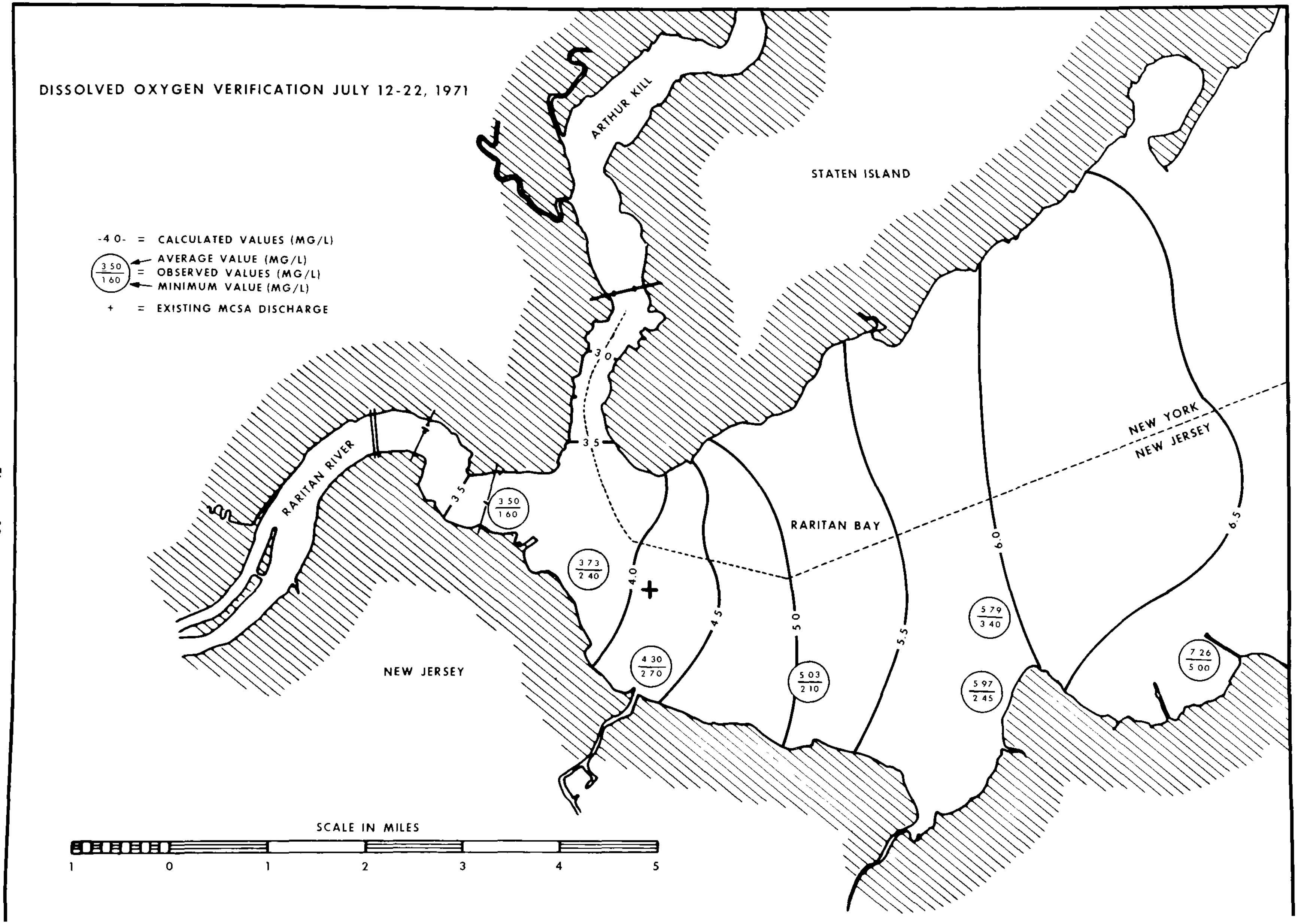
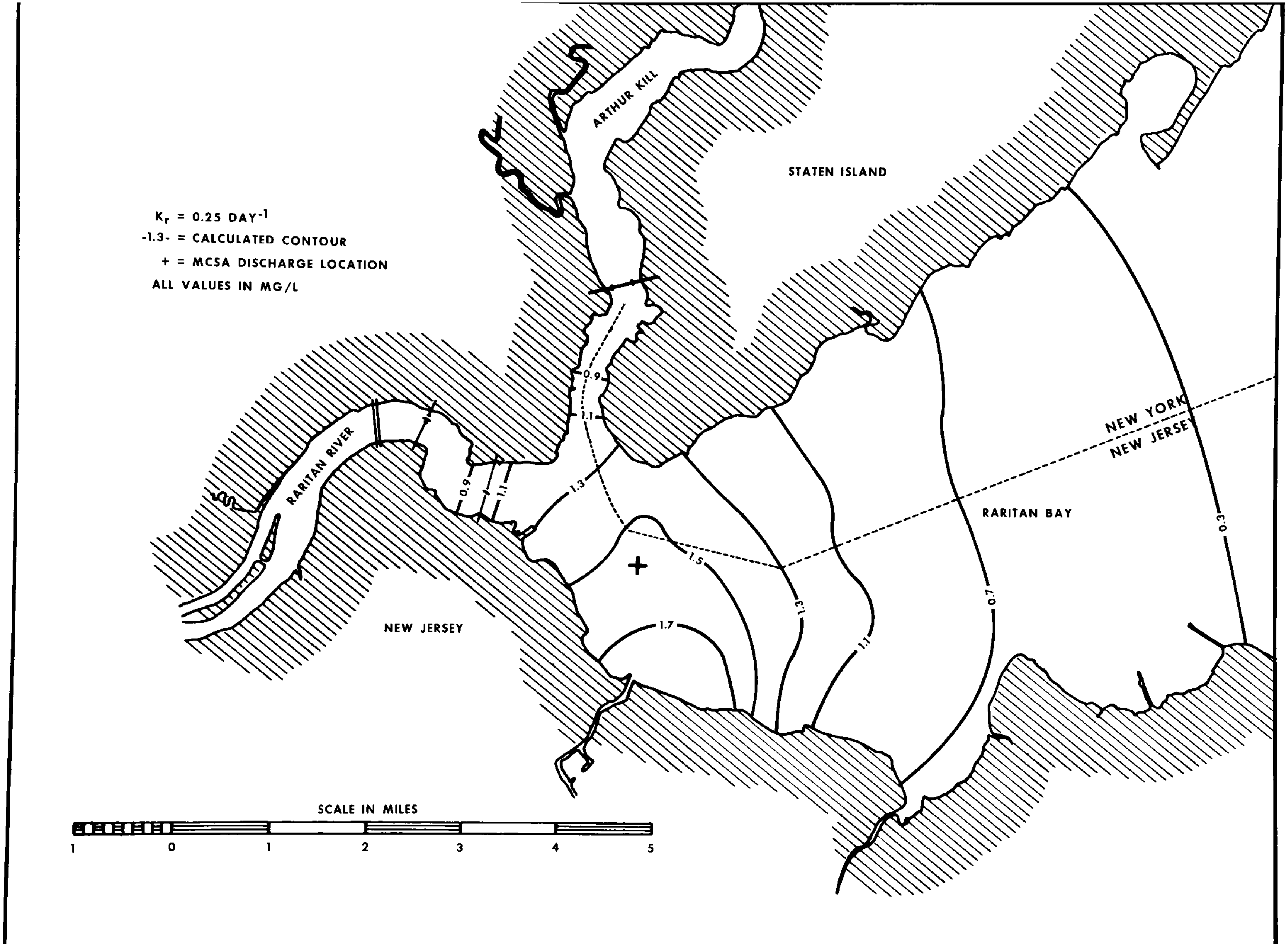

DISSOLVED OXYGEN VERIFICATION JULY 12-22, 1971
-4 0- = CALCULATED VALUES (MG/L)
AVERAGE VALUE (MG/L)
= OBSERVED VALUES (MG/L)
MINIMUM VALUE (MG/L)
3 50 / 1 60
+ = EXISTING MCSA DISCHARGE
ARTHUR KILL
STATEN ISLAND
RARITAN RIVER
RARITAN BAY
NEW YORK
NEW JERSEY
NEW JERSEY
3 0
3 5
3 5
4.0
4 5
5 0
5 5
6.0
6 5
3 50 / 1 60
3 73 / 2 40
4 30 / 2 70
5 03 / 2 10
5 79 / 3 40
5 97 / 2 45
7 26 / 5 00
SCALE IN MILES
1 0 1 2 3 4 5

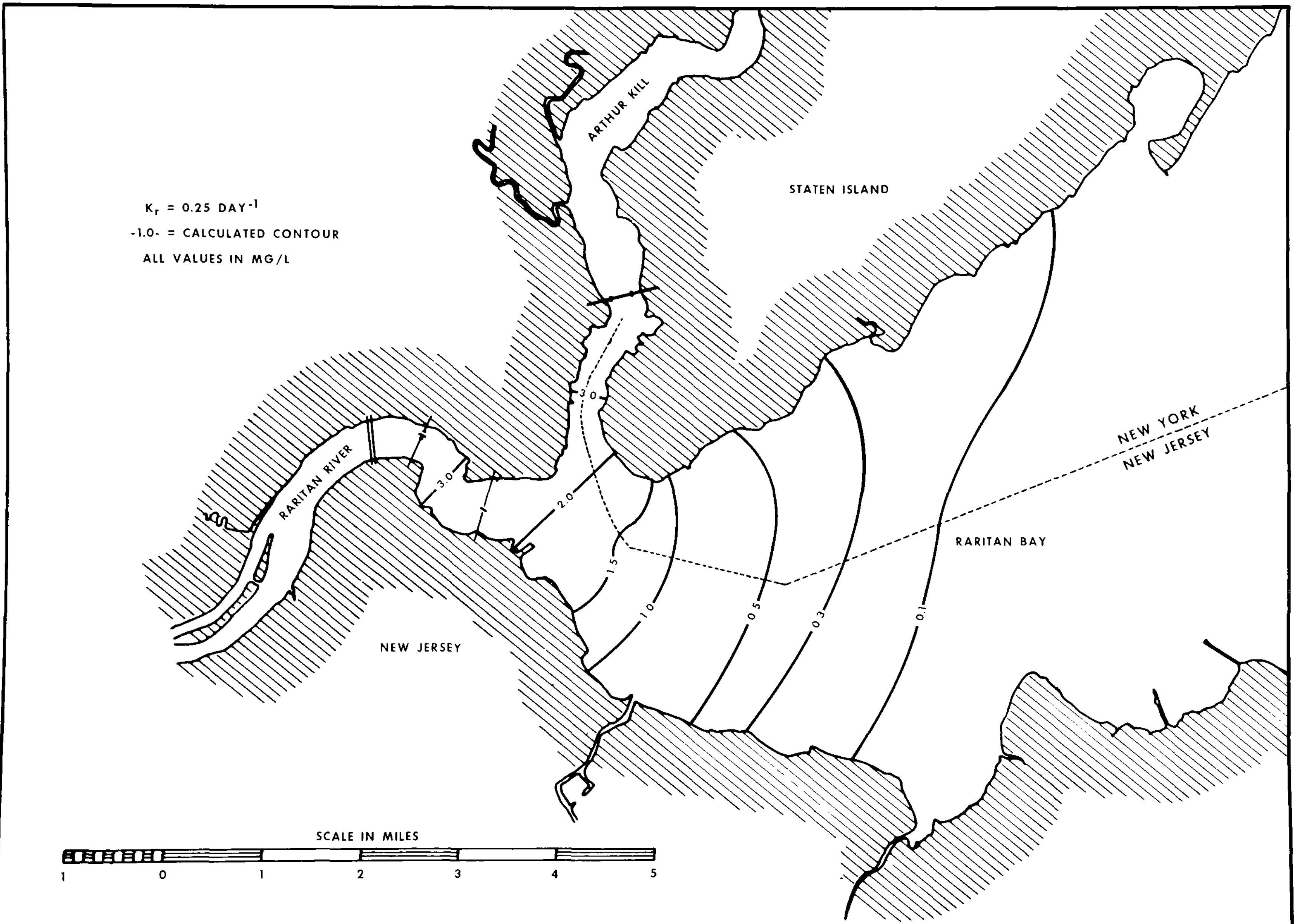
Figure 10

Figure 11



DISSOLVED OXYGEN DEFICIT DUE TO MCSA DISCHARGE - JULY, 1971

Figure 12



DISSOLVED OXYGEN DEFICIT DUE TO BOUNDARY CONDITION EFFECTS - JULY, 1971

Figure 13

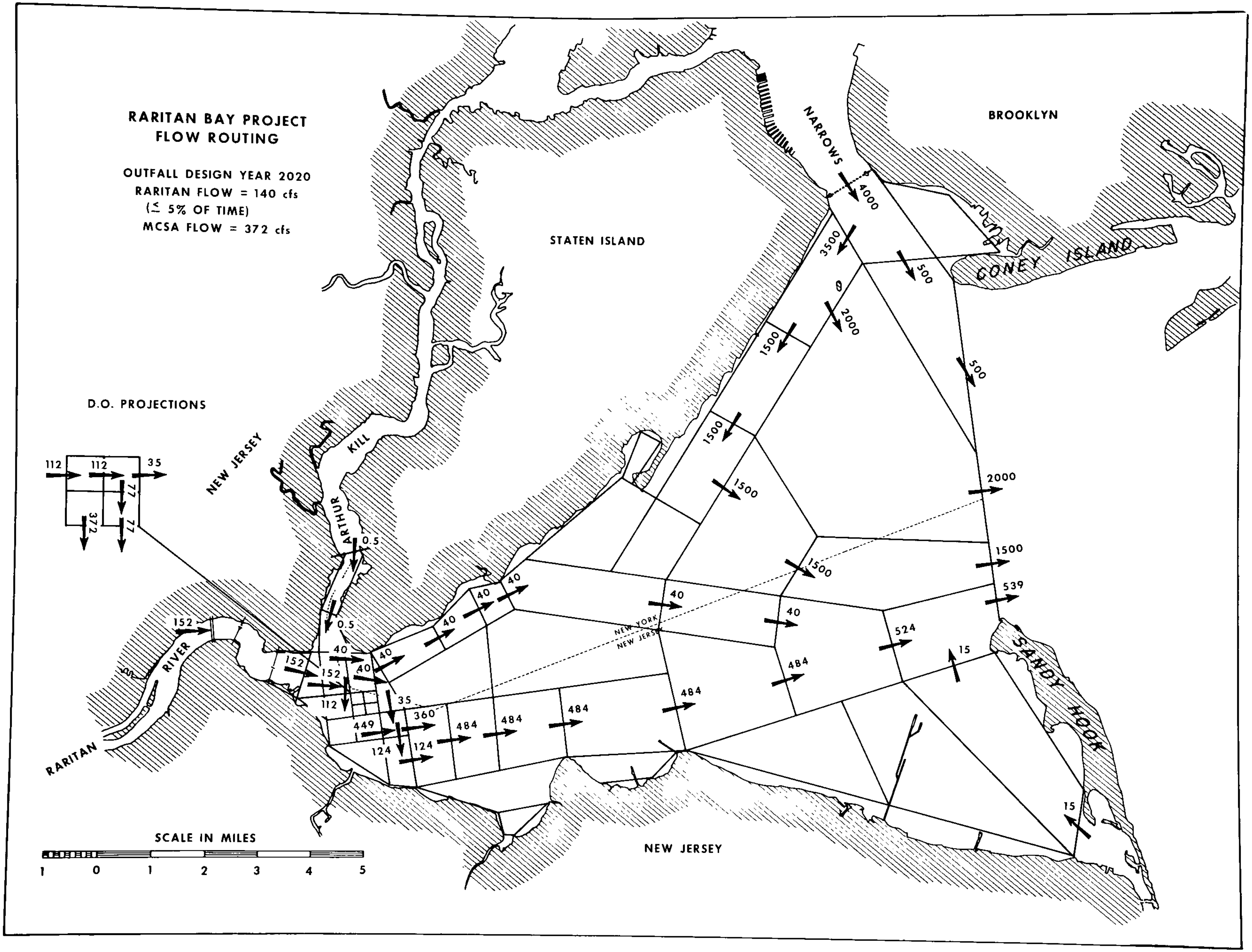
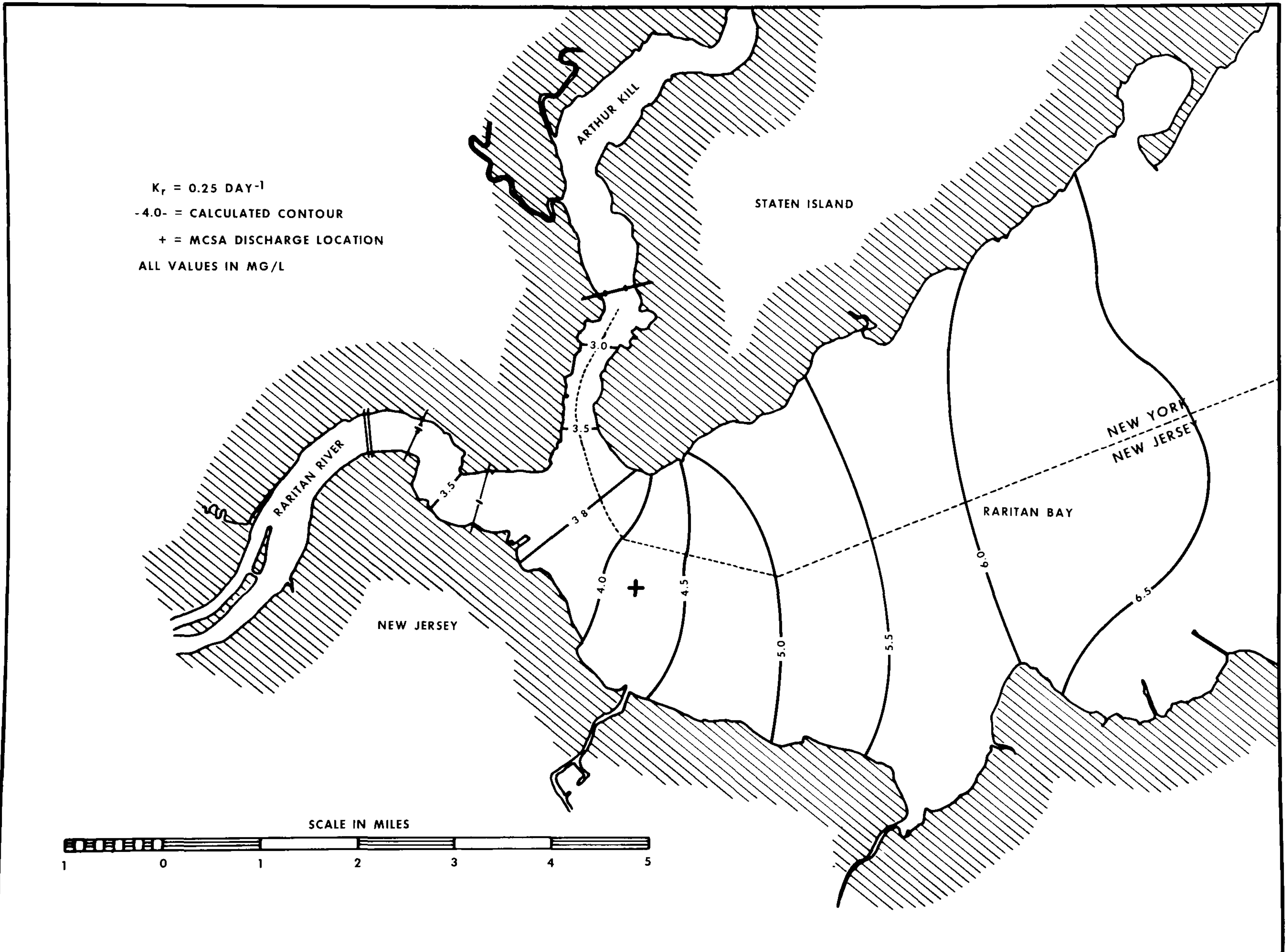

RARITAN BAY PROJECT
FLOW ROUTING
OUTFALL DESIGN YEAR 2020
RARITAN FLOW = 140 cfs
(≤ 5% OF TIME)
MCSA FLOW = 372 cfs
D.O. PROJECTIONS
STATEN ISLAND
BROOKLYN
NARROWS
CONEY ISLAND
SANDY HOOK
NEW JERSEY
ARTHUR KILL
RARITAN RIVER
RARITAN
NEW YORK
NEW JERSEY
SCALE IN MILES
1 0 1 2 3 4 5

Figure 14



CALCULATED DISSOLVED OXYGEN DISTRIBUTION FOR MCSA DISCHARGE AT PRESENT OUTFALL SITE - YEAR 2020

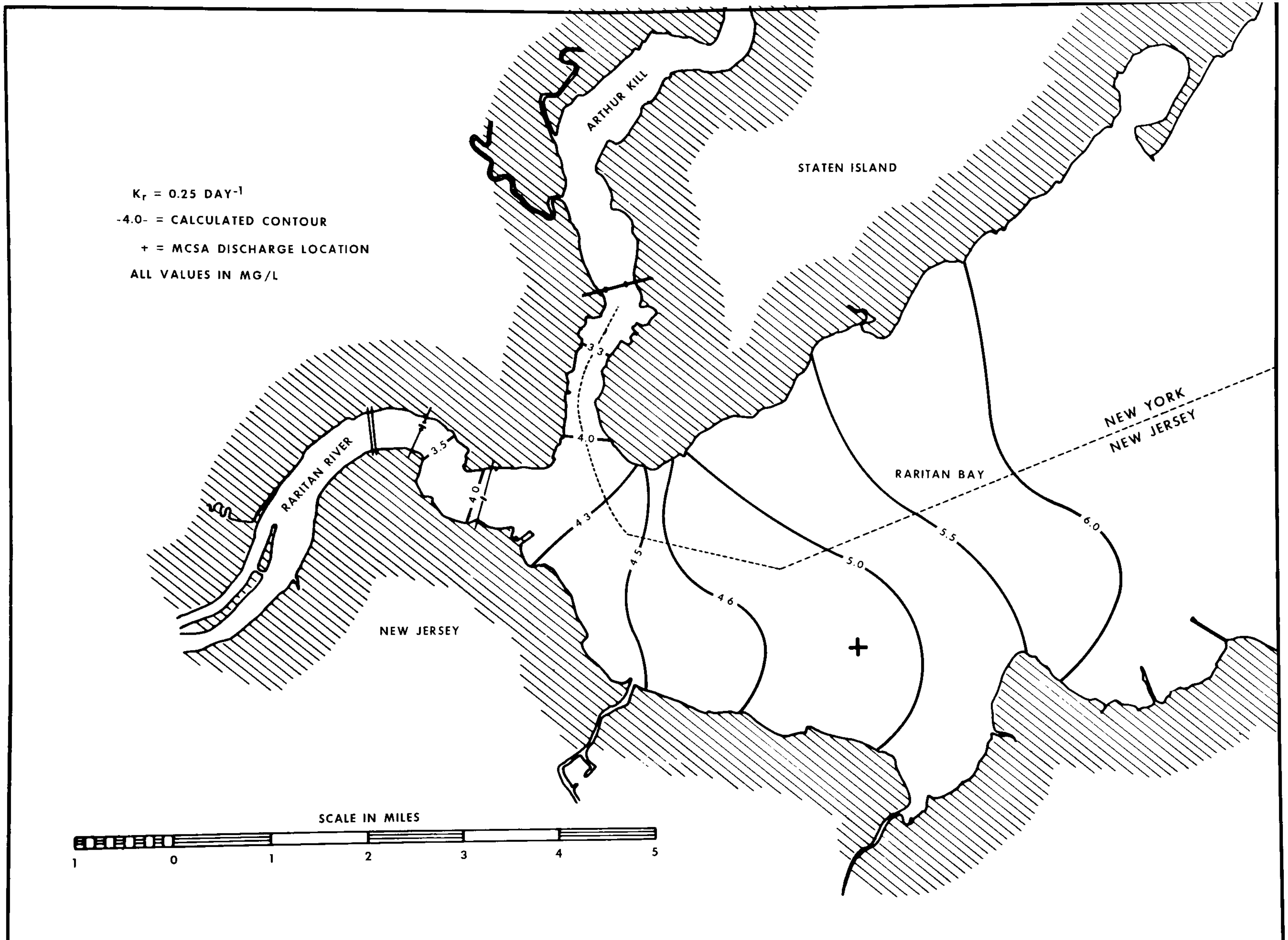
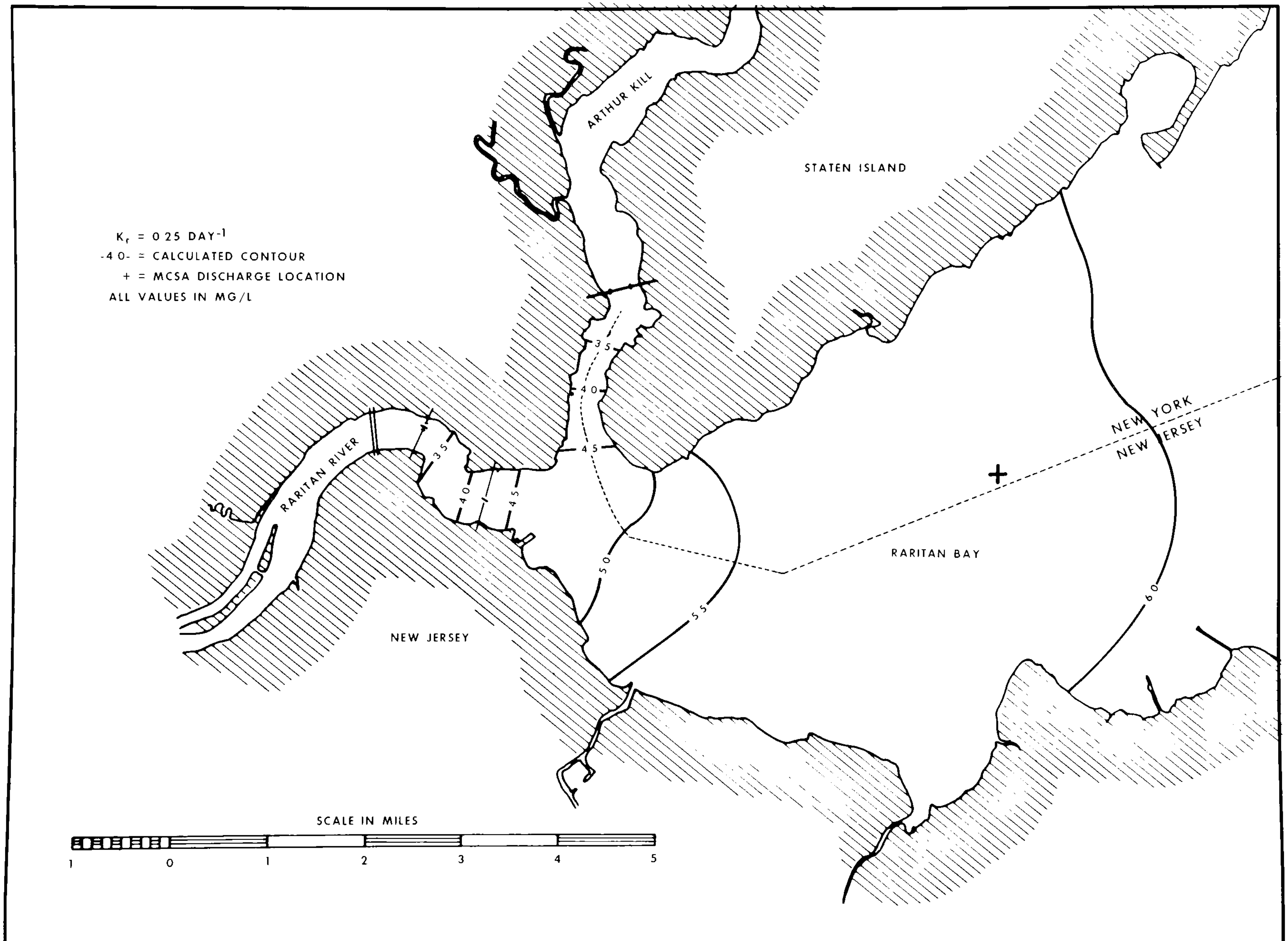


Figure 15

CALCULATED DISSOLVED OXYGEN DISTRIBUTION FOR MCSA DISCHARGE OFF KEYPORT HARBOR - YEAR 2020



CALCULATED DISSOLVED OXYGEN DISTRIBUTION FOR MCSA DISCHARGE IN CENTRAL BAY AREA - YEAR 2020

Figure 16

COMPUTER RUNS

a. Salinity Verification: 10-Year August/September Average
b. Dissolved Oxygen Verification: July, 1971
c. Outfall Relocation Projections: Year 2020

RARITAN BAY TEST RUN

50 SECTION MODEL

SCALE FACTORS --	AREA	E	Q	LENGTH
	1000.000	1.000	1.000	5280.000

EPSILON =0.00100000 OMEGA = 1.000 FL = 1.00 MAXIT = 500

FAC(1)= 1.040 FAC(2)= 1.020 FAC(3)= 1.040 FAC(4)= 1.080

SEGMENT	BOD BOUNDARY CONDITION(MG/L)	DO DEFICIT BOUNDARY CONDITION(MG/L)
1	14860.00	0.0
3	15650.00	0.0
4	15200.00	0.0
5	15250.00	0.0
6	13500.00	0.0
7	13700.00	0.0
49	15550.00	0.0
50	13000.00	0.0

REVISED PARAMETER LIST

NEW FLOWS

INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)
1- 2	0.0	1- 12	3500.000	1- 49	500.000	1- 1	-4000.000	1- 0	0.0	1- 0	0.0
2- 1	0.0	2- 0	0.0	2- 0	0.0	2- 0	0.0	2- 0	0.0	2- 0	0.0
3- 4	0.0	3- 11	0.0	3- 12	-2000.000	3- 13	0.0	3- 49	0.0	3- 3	2000.0
4- 3	0.0	4- 5	0.0	4- 11	-1500.000	4- 10	0.0	4- 4	1500.000	4- 0	0.0
5- 4	0.0	5- 6	-15.000	5- 10	-632.000	5- 5	647.000	5- 0	0.0	5- 0	0.0
6- 5	15.000	6- 8	0.0	6- 6	-15.000	6- 0	0.0	6- 0	0.0	6- 0	0.0
7- 33	0.500	7- 7	-0.500	7- 0	0.0	7- 0	0.0	7- 0	0.0	7- 0	0.0
8- 6	0.0	8- 10	0.0	8- 9	0.0	8- 0	0.0	8- 0	0.0	8- 0	0.0
9- 8	0.0	9- 10	0.0	9- 17	0.0	9- 0	0.0	9- 0	0.0	9- 0	0.0
10- 4	0.0	10- 5	632.000	10- 8	0.0	10- 9	0.0	10- 16	-70.000	10- 17	-562.0
11- 3	0.0	11- 4	1500.000	11- 14	-1500.000	11- 15	0.0	11- 16	0.0	11- 0	0.0
12- 1	-3500.000	12- 3	2000.000	12- 13	1500.000	12- 0	0.0	12- 0	0.0	12- 0	0.0
13- 3	0.0	13- 12	-1500.000	13- 14	1500.000	13- 0	0.0	13- 0	0.0	13- 0	0.0
14- 11	1500.000	14- 13	-1500.000	14- 15	0.0	14- 0	0.0	14- 0	0.0	14- 0	0.0
15- 11	0.0	15- 14	0.0	15- 20	0.0	15- 21	0.0	15- 0	0.0	15- 0	0.0
16- 10	70.000	16- 11	0.0	16- 17	0.0	16- 20	-70.000	16- 0	0.0	16- 0	0.0
17- 9	0.0	17- 10	562.000	17- 16	0.0	17- 18	-507.000	17- 19	-55.000	17- 0	0.0
18- 17	507.000	18- 19	0.0	18- 47	-507.000	18- 48	0.0	18- 0	0.0	18- 0	0.0
19- 17	55.000	19- 18	0.0	19- 20	0.0	19- 23	0.0	19- 26	-55.000	19- 47	0.0
20- 15	0.0	20- 16	70.000	20- 19	0.0	20- 21	0.0	20- 23	-70.000	20- 0	0.0
21- 15	0.0	21- 20	0.0	21- 22	0.0	21- 0	0.0	21- 0	0.0	21- 0	0.0
22- 21	0.0	22- 0	0.0	22- 0	0.0	22- 0	0.0	22- 0	0.0	22- 0	0.0
23- 19	0.0	23- 20	70.000	23- 24	-70.000	23- 0	0.0	23- 0	0.0	23- 0	0.0
24- 23	70.000	24- 25	-70.000	24- 26	0.0	24- 0	0.0	24- 0	0.0	24- 0	0.0
25- 24	70.000	25- 26	0.0	25- 31	-70.000	25- 0	0.0	25- 0	0.0	25- 0	0.0
26- 19	55.000	26- 24	0.0	26- 25	0.0	26- 31	-55.000	26- 45	0.0	26- 46	0.0
27- 28	0.0	27- 45	0.0	27- 46	0.0	27- 47	0.0	27- 0	0.0	27- 0	0.0
28- 27	0.0	28- 0	0.0	28- 0	0.0	28- 0	0.0	28- 0	0.0	28- 0	0.0
29- 30	-133.000	29- 38	0.0	29- 45	133.000	29- 0	0.0	29- 0	0.0	29- 0	0.0
30- 29	133.000	30- 31	-133.000	30- 39	-374.000	30- 45	374.000	30- 0	0.0	30- 0	0.0
31- 25	70.000	31- 26	55.000	31- 30	133.000	31- 32	-125.000	31- 42	-133.000	31- 43	125.0
32- 31	125.000	32- 33	0.0	32- 34	-125.000	32- 41	0.0	32- 42	0.0	32- 0	0.0
33- 32	0.0	33- 34	0.0	33- 7	-0.500	33- 0	0.0	33- 0	0.0	33- 0	0.0
34- 32	125.000	34- 33	0.0	34- 35	-512.000	34- 40	387.000	34- 0	0.0	34- 0	0.0
35- 34	512.000	35- 36	0.0	35- 50	-500.000	35- 0	0.0	35- 0	0.0	35- 0	0.0
36- 35	0.0	36- 40	0.0	36- 0	0.0	36- 0	0.0	36- 0	0.0	36- 0	0.0
37- 39	0.0	37- 40	0.0	37- 0	0.0	37- 0	0.0	37- 0	0.0	37- 0	0.0
38- 29	0.0	38- 39	0.0	38- 0	0.0	38- 0	0.0	38- 0	0.0	38- 0	0.0
39- 30	374.000	39- 37	0.0	39- 38	0.0	39- 43	-254.000	39- 44	-120.000	39- 0	0.0
40- 34	-387.000	40- 36	0.0	40- 37	0.0	40- 41	387.000	40- 44	0.0	40- 0	0.0
41- 32	0.0	41- 40	-387.000	41- 42	387.000	41- 44	0.0	41- 0	0.0	41- 0	0.0
42- 31	133.000	42- 32	0.0	42- 41	-387.000	42- 43	254.000	42- 0	0.0	42- 0	0.0
43- 31	0.0	43- 39	254.000	43- 42	-254.000	43- 44	0.0	43- 0	0.0	43- 0	0.0
44- 39	120.000	44- 40	0.0	44- 41	0.0	44- 43	0.0	44- 0	0.0	44- 0	0.0
45- 26	0.0	45- 27	0.0	45- 29	-133.000	45- 30	-374.000	45- 46	507.000	45- 0	0.0
46- 26	0.0	46- 27	0.0	46- 45	-507.000	46- 47	507.000	46- 0	0.0	46- 0	0.0
47- 18	507.000	47- 19	0.0	47- 27	0.0	47- 46	-507.000	47- 0	0.0	47- 0	0.0
48- 18	0.0	48- 0	0.0	48- 0	0.0	48- 0	0.0	48- 0	0.0	48- 0	0.0
49- 1	-500.000	49- 3	0.0	49- 49	500.000	49- 0	0.0	49- 0	0.0	49- 0	0.0
50- 35	500.000	50- 50	-500.000	50- 0	0.0	50- 0	0.0	50- 0	0.0	50- 0	0.0

SECTION	TEMPERATURE (C)	VOLUME (10**6GAL)	DEPTH (FT)	WTEMP (LBS/DAY)
1	25.00	38148.00	55.00	**********
2	25.00	6597.36	27.00	0.0
3	25.00	71089.88	25.00	**********
4	25.00	23023.44	25.00	**********
5	25.00	17376.04	28.00	**********
6	25.00	31236.48	26.00	**********
7	25.00	1959.76	25.00	**********
8	25.00	21048.71	20.00	0.0
9	25.00	6874.12	10.00	0.0
10	25.00	18445.68	25.00	0.0
11	25.00	19784.60	20.00	0.0
12	25.00	5213.56	16.00	0.0
13	25.00	5961.56	14.00	0.0
14	25.00	5093.88	12.00	0.0
15	25.00	5093.88	16.00	0.0
16	25.00	13426.60	29.00	0.0
17	25.00	13740.76	17.00	0.0
18	25.00	9200.40	13.00	0.0
19	25.00	13740.76	17.00	0.0
20	25.00	14967.48	23.00	0.0
21	25.00	4345.88	10.00	0.0
22	25.00	671.70	15.00	0.0
23	25.00	1855.04	18.00	0.0
24	25.00	2999.48	20.00	0.0
25	25.00	2326.28	15.00	0.0
26	25.00	4577.76	13.00	0.0
27	25.00	2094.40	7.00	0.0
28	25.00	160.07	3.00	0.0
29	25.00	7150.88	7.00	0.0
30	25.00	513.13	9.00	0.0
31	25.00	1136.96	18.00	0.0
32	25.00	2169.20	28.00	0.0
33	25.00	2049.52	27.00	0.0
34	25.00	1668.04	20.00	0.0
35	25.00	897.60	15.00	0.0
36	25.00	89.76	4.00	0.0
37	25.00	216.92	4.00	0.0
38	25.00	545.29	6.00	0.0
39	25.00	434.59	8.00	0.0
40	25.00	379.24	7.00	0.0
41	25.00	195.23	15.00	0.0
42	25.00	195.23	15.00	0.0
43	25.00	130.15	10.00	0.0
44	25.00	117.44	9.00	0.0
45	25.00	2707.76	10.00	0.0
46	25.00	2797.52	11.00	0.0
47	25.00	3904.56	12.00	0.0
48	25.00	1002.32	6.00	0.0
49	25.00	18326.00	38.00	**********
50	25.00	964.92	17.50	**********

ITERATION NUMBER 453

SECTION	DECAY COEFFICIENT (1/DAY)	MATRIX DIAGONAL (MGD)	SOURCE LOADS (LBS/DAY)	BOD PROFILE (MG/L)
1	0.0	182122.000	***********	15034.91
2	0.0	42082.375	0.0	15034.91
3	0.0	120878.063	***********	15373.21
4	0.0	38449.410	***********	15138.89
5	0.0	40737.762	***********	15137.48
6	0.0	22807.121	***********	14772.68
7	0.0	7797.230	***********	13682.39
8	0.0	19133.363	0.0	14786.48
9	0.0	4303.453	0.0	14825.68
10	0.0	22655.148	0.0	14984.92
11	0.0	30044.621	0.0	15065.93
12	0.0	26806.340	0.0	15125.44
13	0.0	14309.035	0.0	15272.63
14	0.0	11797.199	0.0	15097.24
15	0.0	10177.422	0.0	14787.38
16	0.0	26489.777	0.0	14858.98
17	0.0	23925.949	0.0	14799.87
18	0.0	13023.504	0.0	14525.77
19	0.0	22251.035	0.0	14508.91
20	0.0	23205.117	0.0	14628.54
21	0.0	8474.738	0.0	14714.24
22	0.0	74.352	0.0	14714.23
23	0.0	16159.504	0.0	14317.05
24	0.0	19013.574	0.0	14233.37
25	0.0	15327.660	0.0	14055.74
26	0.0	17676.539	0.0	14119.75
27	0.0	5784.914	0.0	14162.62
28	0.0	1446.295	0.0	14162.61
29	0.0	13054.406	0.0	13958.08
30	0.0	23343.434	0.0	13875.23
31	0.0	21558.402	0.0	13819.89
32	0.0	24857.254	0.0	13688.14
33	0.0	11118.164	0.0	13663.41
34	0.0	48233.992	0.0	13644.56
35	0.0	21957.590	0.0	13588.18
36	0.0	1727.007	0.0	13641.91
37	0.0	1611.585	0.0	13719.70
38	0.0	3958.345	0.0	13902.88
39	0.0	23307.273	0.0	13818.62
40	0.0	19228.406	0.0	13665.76
41	0.0	23610.586	0.0	13694.61
42	0.0	27134.836	0.0	13733.29
43	0.0	19806.871	0.0	13755.48
44	0.0	8913.227	174960.000	13628.59
45	0.0	21531.195	0.0	14043.82
46	0.0	17612.758	0.0	14130.67
47	0.0	11351.332	0.0	14295.88
48	0.0	1247.531	0.0	14525.75
49	0.0	203626.938	***********	15377.64

RARITAN BAY TEST RUN

50 SECTION MODEL

SCALE FACTORS --	AREA	E	Q	LENGTH
	1000.000	1.000	1.000	5280.000

EPSILON =C.CC1C0C00   OMEGA = 1.C00   FL = 1.00   MAXIT = 500

FAC(1)= 1.040   FAC(2)= 1.020   FAC(3)= 1.040   FAC(4)= 1.080

SEGMENT	BOD BOUNDARY CONDITION(MG/L)	DO DEFICIT BOUNDARY CONDITION(MG/L)
1	2.28	3.20
7	2.26	4.75
50	2.26	3.90

REVISED PARAMETER LIST

NEW FLOWS

INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)
1- 2	0.0	1- 12	3500.000	1- 49	500.000	1- 1	-4000.000	1- 0	0.0	1- 0	0.0
2- 1	0.0	2- 0	0.0	2- 0	0.0	2- 0	0.0	2- 0	0.0	2- 0	0.0
3- 4	0.0	3- 11	0.0	3- 12	-2000.000	3- 13	0.0	3- 49	0.0	3- 3	2000.0
4- 3	0.0	4- 5	0.0	4- 11	-1500.000	4- 10	0.0	4- 4	1500.000	4- 0	0.0
5- 4	0.0	5- 6	-15.000	5- 10	-382.000	5- 5	397.000	5- 0	0.0	5- 0	0.0
6- 5	15.000	6- 8	0.0	6- 6	-15.000	6- 0	0.0	6- 0	0.0	6- 0	0.0
7- 33	0.500	7- 7	-0.500	7- 0	0.0	7- 0	0.0	7- 0	0.0	7- 0	0.0
8- 6	0.0	8- 10	0.0	8- 9	0.0	8- 0	0.0	8- 0	0.0	8- 0	0.0
9- 8	0.0	9- 10	0.0	9- 17	0.0	9- 0	0.0	9- 0	0.0	9- 0	0.0
10- 4	0.0	10- 5	382.000	10- 8	0.0	10- 9	0.0	10- 16	-62.000	10- 17	-320.0
11- 3	0.0	11- 4	1500.000	11- 14	-1500.000	11- 15	0.0	11- 16	0.0	11- 0	0.0
12- 1	-3500.000	12- 3	2000.000	12- 13	1500.000	12- 0	0.0	12- 0	0.0	12- 0	0.0
13- 3	0.0	13- 12	-1500.000	13- 14	1500.000	13- 0	0.0	13- 0	0.0	13- 0	0.0
14- 11	1500.000	14- 13	-1500.000	14- 15	0.0	14- 0	0.0	14- 0	0.0	14- 0	0.0
15- 11	0.0	15- 14	0.0	15- 20	0.0	15- 21	0.0	15- 0	0.0	15- 0	0.0
16- 10	62.000	16- 11	0.0	16- 17	0.0	16- 20	-62.000	16- 0	0.0	16- 0	0.0
17- 9	0.0	17- 10	320.000	17- 16	0.0	17- 18	-320.000	17- 19	0.0	17- 0	0.0
18- 17	320.000	18- 19	0.0	18- 47	-320.000	18- 48	0.0	18- 0	0.0	18- 0	0.0
19- 17	0.0	19- 18	0.0	19- 20	0.0	19- 23	0.0	19- 26	0.0	19- 47	0.0
20- 15	0.0	20- 16	62.000	20- 19	0.0	20- 21	0.0	20- 23	-62.000	20- 0	0.0
21- 15	0.0	21- 20	0.0	21- 22	0.0	21- 0	0.0	21- 0	0.0	21- 0	0.0
22- 21	0.0	22- 0	0.0	22- 0	0.0	22- 0	0.0	22- 0	0.0	22- 0	0.0
23- 19	0.0	23- 20	62.000	23- 24	-62.000	23- 0	0.0	23- 0	0.0	23- 0	0.0
24- 23	62.000	24- 25	-62.000	24- 26	0.0	24- 0	0.0	24- 0	0.0	24- 0	0.0
25- 24	62.000	25- 26	0.0	25- 31	-62.000	25- 0	0.0	25- 0	0.0	25- 0	0.0
26- 19	0.0	26- 24	0.0	26- 25	0.0	26- 31	0.0	26- 45	0.0	26- 46	0.0
27- 28	0.0	27- 45	0.0	27- 46	0.0	27- 47	0.0	27- 0	0.0	27- 0	0.0
28- 27	0.0	28- 0	0.0	28- 0	0.0	28- 0	0.0	28- 0	0.0	28- 0	0.0
29- 30	-73.000	29- 38	0.0	29- 45	73.000	29- 0	0.0	29- 0	0.0	29- 0	0.0
30- 29	73.000	30- 31	-73.000	30- 39	-247.000	30- 45	247.000	30- 0	0.0	30- 0	0.0
31- 25	62.000	31- 26	0.0	31- 30	73.000	31- 32	-62.000	31- 42	-73.000	31- 43	0.0
32- 31	62.000	32- 33	0.0	32- 34	-62.000	32- 41	0.0	32- 42	0.0	32- 0	0.0
33- 32	0.0	33- 34	0.0	33- 7	0.500	33- 0	0.0	33- 0	0.0	33- 0	0.0
34- 32	62.000	34- 33	0.0	34- 35	-250.000	34- 40	200.000	34- 0	0.0	34- 0	0.0
35- 34	262.000	35- 36	0.0	35- 50	-262.000	35- 0	0.0	35- 0	0.0	35- 0	0.0
36- 35	0.0	36- 40	0.0	36- 0	0.0	36- 0	0.0	36- 0	0.0	36- 0	0.0
37- 39	0.0	37- 40	0.0	37- 0	0.0	37- 0	0.0	37- 0	0.0	37- 0	0.0
38- 29	0.0	38- 39	0.0	38- 0	0.0	38- 0	0.0	38- 0	0.0	38- 0	0.0
39- 30	247.000	39- 37	0.0	39- 38	0.0	39- 43	-127.000	39- 44	-120.000	39- 0	0.0
40- 34	-200.000	40- 36	0.0	40- 37	0.0	40- 41	200.000	40- 44	0.0	40- 0	0.0
41- 32	0.0	41- 40	-200.000	41- 42	200.000	41- 44	0.0	41- 0	0.0	41- 0	0.0
42- 31	73.000	42- 32	0.0	42- 41	-200.000	42- 43	127.000	42- 0	0.0	42- 0	0.0
43- 31	0.0	43- 39	127.000	43- 42	-127.000	43- 44	0.0	43- 0	0.0	43- 0	0.0
44- 39	120.000	44- 40	0.0	44- 41	0.0	44- 43	0.0	44- 0	0.0	44- 0	0.0
45- 26	0.0	45- 27	0.0	45- 29	-73.000	45- 30	-247.000	45- 46	320.000	45- 0	0.0
46- 26	0.0	46- 27	0.0	46- 45	-320.000	46- 47	320.000	46- 0	0.0	46- 0	0.0
47- 18	320.000	47- 19	0.0	47- 27	0.0	47- 46	-320.000	47- 0	0.0	47- 0	0.0
48- 18	0.0	48- 0	0.0	48- 0	0.0	48- 0	0.0	48- 0	0.0	48- 0	0.0
49- 1	-500.000	49- 3	0.0	49- 49	500.000	49- 0	0.0	49- 0	0.0	49- 0	0.0
50- 35	250.000	50- 50	-250.000	50- 0	0.0	50- 0	0.0	50- 0	0.0	50- 0	0.0

SECTION	TEMPERATURE (C)	VOLUME (10**6GAL)	DEPTH (FT)	WTEMP (LBS/DAY)
1	21.00	38148.00	55.00	1609486.00
2	21.00	6597.36	27.00	0.0
3	20.50	71089.88	25.00	0.0
4	21.00	23023.44	25.00	0.0
5	21.50	17376.04	28.00	0.0
6	21.50	31236.48	26.00	0.0
7	23.00	1959.76	25.00	76240.31
8	21.50	21048.71	20.00	0.0
9	21.50	6874.12	10.00	0.0
10	21.50	18445.68	25.00	0.0
11	21.50	19784.60	20.00	0.0
12	21.00	5213.56	16.00	0.0
13	21.00	5961.56	14.00	0.0
14	21.50	5093.88	12.00	0.0
15	21.50	5093.88	16.00	0.0
16	21.50	13426.60	29.00	0.0
17	21.50	13740.76	17.00	0.0
18	22.00	9200.40	13.00	0.0
19	22.00	13740.76	17.00	0.0
20	22.00	14967.48	23.00	0.0
21	22.00	4345.88	10.00	0.0
22	21.50	671.70	15.00	0.0
23	22.00	1855.04	18.00	0.0
24	22.00	2999.48	20.00	0.0
25	22.00	2326.28	15.00	0.0
26	22.00	4577.76	13.00	0.0
27	22.00	2094.40	7.00	0.0
28	22.00	160.07	3.00	0.0
29	22.50	7150.88	7.00	0.0
30	22.50	513.13	9.00	0.0
31	22.50	1136.96	18.00	0.0
32	23.00	2169.20	28.00	0.0
33	23.00	2049.52	27.00	0.0
34	23.00	1668.04	20.00	0.0
35	23.00	897.60	15.00	0.0
36	23.00	89.76	4.00	0.0
37	23.00	216.92	4.00	0.0
38	22.50	545.29	6.00	0.0
39	22.50	434.59	8.00	0.0
40	23.00	379.24	7.00	0.0
41	23.00	195.23	15.00	0.0
42	23.00	195.23	15.00	0.0
43	23.00	130.15	10.00	0.0
44	23.00	117.44	9.00	0.0
45	22.00	2707.76	10.00	0.0
46	22.00	2797.52	11.00	0.0
47	22.00	3904.56	12.00	0.0
48	22.00	1002.32	6.00	0.0
49	20.50	18326.00	38.00	0.0
50	23.00	964.92	17.50	39052.10

ITERATION NUMBER 79

SECTION	DECAY COEFFICIENT (1/DAY)	MATRIX DIAGONAL (MGD)	SOURCE LOADS (LBS/DAY)	BOD PROFILE (MG/L)
1	0.260	192040.438	1609486.000	1.50
2	0.260	43797.688	0.0	1.44
3	0.255	139002.438	0.0	0.35
4	0.260	44435.500	0.0	0.10
5	0.265	45358.520	0.0	0.03
6	0.265	31089.441	0.0	0.02
7	0.281	8348.344	76240.313	2.61
8	0.265	24714.410	1730.000	0.04
9	0.265	6126.117	0.0	0.11
10	0.265	27554.453	0.0	0.11
11	0.265	35290.488	0.0	0.20
12	0.260	28161.863	0.0	1.12
13	0.260	15859.039	0.0	0.49
14	0.265	13147.836	11050.000	0.35
15	0.265	11528.059	0.0	0.30
16	0.265	30049.871	0.0	0.23
17	0.265	27558.016	2363.000	0.25
18	0.270	15487.707	0.0	0.56
19	0.270	25961.988	0.0	0.65
20	0.270	27250.688	0.0	0.46
21	0.270	9649.863	0.0	0.33
22	0.265	252.454	0.0	0.10
23	0.270	16660.242	0.0	1.23
24	0.270	19826.277	0.0	1.49
25	0.270	15956.105	0.0	2.26
26	0.270	18895.805	0.0	1.96
27	0.270	6351.238	0.0	1.56
28	0.270	1489.579	1244.000	1.61
29	0.276	15017.023	0.0	2.73
30	0.276	23428.914	0.0	4.05
31	0.276	21830.070	0.0	3.60
32	0.281	25472.219	0.0	3.98
33	0.281	11694.844	0.0	3.38
34	0.281	48677.332	0.0	4.04
35	0.281	22182.375	26100.000	4.01
36	0.281	1752.249	3377.000	4.74
37	0.281	1672.587	0.0	4.69
38	0.276	4108.711	0.0	3.48
39	0.276	23373.777	0.0	4.96
40	0.281	19352.387	0.0	4.83
41	0.281	23686.289	0.0	5.64
42	0.281	27201.871	0.0	5.14
43	0.281	19831.348	0.0	5.29
44	0.281	8946.250	334800.000	9.72
45	0.270	22244.691	0.0	2.33
46	0.270	18329.785	0.0	1.83
47	0.270	12360.445	0.0	1.16
48	0.270	1518.558	0.0	0.46
49	0.255	208299.125	0.0	0.42

ITERATION NUMBER 78

SECTION	DEOXYGENATION COEFFICIENT (1/DAY)	REAERATION COEFFICIENT (1/DAY)	MATRIX DIAGONAL (MGD)	SOURCE LOADS (MGD*MG/L)	PHOTO MINUS RESPIRATION (MG/(L-DAY)	BOTTOM DEMAND (GM/M**2/DAY)	DISSOLVED OXYGEN DEFICIT (MG/L)
1	0.260	0.204	189904.125	285769.063	0.0	0.0	2.32301331
2	0.260	0.204	43428.234	2478.275	0.0	0.0	2.30808640
3	0.255	0.202	135237.500	6315.879	0.0	0.0	0.65773958
4	0.260	0.204	43146.188	618.164	0.0	0.0	0.22836244
5	0.265	0.206	44331.258	150.745	0.0	0.0	0.07912838
6	0.265	0.206	29242.758	196.614	0.0	0.0	0.06533551
7	0.281	0.212	8213.172	20652.816	0.0	0.0	4.19839382
8	0.265	0.206	23470.020	196.070	0.0	0.0	0.08073175
9	0.265	0.206	5719.723	200.097	0.0	0.0	0.25604850
10	0.265	0.206	26463.957	560.095	0.0	0.0	0.25582623
11	0.265	0.206	34120.832	1066.136	0.0	0.0	0.40549338
12	0.260	0.204	27869.902	1515.553	0.0	0.0	1.83748722
13	0.260	0.204	15525.191	762.308	0.0	0.0	0.91694671
14	0.265	0.206	12846.688	477.443	0.0	0.0	0.53640831
15	0.265	0.206	11226.910	408.319	0.0	0.0	0.56944960
16	0.265	0.206	29256.098	813.928	0.0	0.0	0.44297785
17	0.265	0.206	26745.668	928.492	0.0	0.0	0.45530635
18	0.270	0.208	14914.336	463.317	0.100	0.0	0.73151749
19	0.270	0.208	25105.660	1051.718	0.100	0.0	0.87607360
20	0.270	0.208	26317.910	353.050	0.100	0.0	0.69634330
21	0.270	0.208	9379.027	383.012	0.0	0.0	0.60551155
22	0.265	0.206	212.743	17.097	0.0	0.0	0.29198426
23	0.270	0.208	16544.637	429.901	0.100	0.0	1.46298504
24	0.270	0.208	19639.348	1207.677	0.0	0.0	1.68676949
25	0.270	0.208	15811.133	1421.612	0.0	0.0	2.13939667
26	0.270	0.208	18610.516	2422.337	0.0	0.0	1.96709156
27	0.270	0.208	6220.715	-1001.562	0.900	0.0	1.38035488
28	0.270	0.208	1479.603	-74.176	0.900	0.0	1.29914856
29	0.276	0.210	14547.895	5392.746	0.0	0.0	2.56384087
30	0.276	0.210	23395.250	572.460	0.0	0.0	2.65602779
31	0.276	0.210	21755.480	1127.770	0.0	0.0	2.67619991
32	0.281	0.212	25322.598	2428.952	0.0	0.0	3.27083302
33	0.281	0.212	11553.480	1945.452	0.0	0.0	3.68624020
34	0.281	0.212	48562.277	1895.552	0.0	0.0	3.40642929
35	0.281	0.212	22120.461	1011.199	0.0	0.0	3.46552086
36	0.281	0.212	1746.057	119.598	0.0	0.0	3.36666489
37	0.281	0.212	1657.625	286.361	0.0	0.0	3.18358612
38	0.276	0.210	4072.938	523.740	0.0	0.0	2.69867039
39	0.276	0.210	23345.270	594.444	0.0	0.0	2.76845169
40	0.281	0.212	19326.230	514.602	0.0	0.0	3.27737713
41	0.281	0.212	23672.824	309.823	0.0	0.0	3.08654499
42	0.281	0.212	27188.406	282.213	0.0	0.0	2.97378540
43	0.281	0.212	19822.371	193.519	0.0	0.0	2.88607025
44	0.281	0.212	8938.148	320.861	0.0	0.0	2.95349693
45	0.270	0.208	22075.945	1707.081	0.0	0.0	2.18664742
46	0.270	0.208	18155.441	1381.587	0.0	0.0	1.87586021
47	0.270	0.208	12117.109	838.296	0.100	0.0	1.33018494
48	0.270	0.208	1456.093	-878.510	1.000	0.0	0.02340548
49	0.255	0.202	207328.563	1980.716	0.0	0.0	0.71617663

50	0.281	0.212	6337.090	8968.105	0.0	0.0	3.63565445
1	0.15036E 05	0.21000E 02	0.23230E 01	0.70693E 01	0.47463E 01		
2	0.15036E 05	0.21000E 02	0.23081E 01	0.70693E 01	0.47612E 01		
3	0.15377E 05	0.20500E 02	0.65774E 00	0.70442E 01	0.63865E 01		
4	0.15160E 05	0.21000E 02	0.22836E 00	0.70601E 01	0.68318E 01		
5	0.15151E 05	0.21500E 02	0.79128E-01	0.70608E 01	0.69817E 01		
6	0.14795E 05	0.21500E 02	0.65336E-01	0.70871E 01	0.70217E 01		
7	0.13761E 05	0.23000E 02	0.41994E 01	0.71631E 01	0.29647E 01		
8	0.14813E 05	0.21500E 02	0.80732E-01	0.70857E 01	0.70050E 01		
9	0.14886E 05	0.21500E 02	0.25605E 00	0.70803E 01	0.68243E 01		
10	0.15033E 05	0.21500E 02	0.25583E 00	0.70695E 01	0.68137E 01		
11	0.15107E 05	0.21500E 02	0.40549E 00	0.70641E 01	0.66586E 01		
12	0.15127E 05	0.21000E 02	0.18375E 01	0.70626E 01	0.52251E 01		
13	0.15280E 05	0.21000E 02	0.91695E 00	0.70513E 01	0.61344E 01		
14	0.15134E 05	0.21500E 02	0.53641E 00	0.70621E 01	0.65257E 01		
15	0.14983E 05	0.21500E 02	0.56945E 00	0.70806E 01	0.65111E 01		
16	0.14937E 05	0.21500E 02	0.44298E 00	0.70766E 01	0.66336E 01		
17	0.14888E 05	0.21500E 02	0.45531E 00	0.70802E 01	0.66249E 01		
18	0.14673E 05	0.22000E 02	0.73152E 00	0.70960E 01	0.63645E 01		
19	0.14659E 05	0.22000E 02	0.87607E 00	0.70970E 01	0.62209E 01		
20	0.14755E 05	0.22000E 02	0.69634E 00	0.70900E 01	0.63936E 01		
21	0.14824E 05	0.22000E 02	0.60551E 00	0.70849E 01	0.64794E 01		
22	0.14824E 05	0.21500E 02	0.29198E 00	0.70849E 01	0.67929E 01		
23	0.14506E 05	0.22000E 02	0.14630E 01	0.71083E 01	0.56453E 01		
24	0.14440E 05	0.22000E 02	0.16868E 01	0.71132E 01	0.54264E 01		
25	0.14299E 05	0.22000E 02	0.21394E 01	0.71236E 01	0.49842E 01		
26	0.14348E 05	0.22000E 02	0.19671E 01	0.71199E 01	0.51529E 01		
27	0.14374E 05	0.22000E 02	0.13804E 01	0.71180E 01	0.57377E 01		
28	0.14374E 05	0.22000E 02	0.12991E 01	0.71180E 01	0.58189E 01		
29	0.14196E 05	0.22500E 02	0.25638E 01	0.71311E 01	0.45672E 01		
30	0.14123E 05	0.22500E 02	0.26560E 01	0.71365E 01	0.44804E 01		
31	0.14113E 05	0.22500E 02	0.26762E 01	0.71372E 01	0.44610E 01		
32	0.13913E 05	0.23000E 02	0.32708E 01	0.71519E 01	0.38811E 01		
33	0.13828E 05	0.23000E 02	0.36862E 01	0.71582E 01	0.34720E 01		
34	0.13850E 05	0.23000E 02	0.34064E 01	0.71566E 01	0.37502E 01		
35	0.13786E 05	0.23000E 02	0.34655E 01	0.71612E 01	0.36957E 01		
36	0.13856E 05	0.23000E 02	0.33667E 01	0.71561E 01	0.37895E 01		
37	0.13950E 05	0.23000E 02	0.31836E 01	0.71492E 01	0.39656E 01		
38	0.14145E 05	0.22500E 02	0.26987E 01	0.71348E 01	0.44362E 01		
39	0.14067E 05	0.22500E 02	0.27685E 01	0.71406E 01	0.43721E 01		
40	0.13887E 05	0.23000E 02	0.32774E 01	0.71539E 01	0.38765E 01		
41	0.13935E 05	0.23000E 02	0.30865E 01	0.71503E 01	0.40638E 01		
42	0.13986E 05	0.23000E 02	0.29738E 01	0.71466E 01	0.41728E 01		
43	0.14013E 05	0.23000E 02	0.28861E 01	0.71446E 01	0.42585E 01		
44	0.13872E 05	0.23000E 02	0.29535E 01	0.71550E 01	0.42015E 01		
45	0.14273E 05	0.22000E 02	0.21866E 01	0.71254E 01	0.49388E 01		
46	0.14348E 05	0.22000E 02	0.18759E 01	0.71199E 01	0.52441E 01		
47	0.14486E 05	0.22000E 02	0.13302E 01	0.71098E 01	0.57796E 01		
48	0.14673E 05	0.22000E 02	0.23405E-01	0.70960E 01	0.70726E 01		
49	0.15379E 05	0.20500E 02	0.71618E 00	0.70440E 01	0.63279E 01		
50	0.13521E 05	0.23000E 02	0.36357E 01	0.71808E 01	0.35451E 01		

RARITAN BAY TEST RUN

50 SECTION MODEL

SCALE FACTORS --	AREA	E	Q	LENGTH
	1000.000	1.000	1.000	5280.000

EPSILCN =0.00100000 OMEGA = 1.000 FL = 1.00 MAXIT = 500

FAC(1)= 1.040 FAC(2)= 1.020 FAC(3)= 1.040 FAC(4)= 1.080

SEGMENT	BOD BOUNDARY CONDITION(MG/L)	DO DEFICIT BOUNDARY CONDITION(MG/L)
1	2.28	3.20
7	2.26	4.75
50	2.26	3.90

REVISED PARAMETER LIST

NEW FLOWS

INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)	INTERFACE	Q (CFS)
1- 2	0.0	1- 12	3500.000	1- 49	500.000	1- 1	-4000.000	1- 0	0.0	1- 0	0.0
2- 1	0.0	2- 0	0.0	2- 0	0.0	2- 0	0.0	2- 0	0.0	2- 0	0.0
3- 4	0.0	3- 11	0.0	3- 12	-2000.000	3- 13	0.0	3- 49	0.0	3- 3	2000.0
4- 3	0.0	4- 5	0.0	4- 11	-1500.000	4- 10	0.0	4- 4	1500.000	4- 0	0.0
5- 4	0.0	5- 6	-15.000	5- 10	-524.000	5- 5	539.000	5- 0	0.0	5- 0	0.0
6- 5	15.000	6- 8	0.0	6- 6	-15.000	6- 0	0.0	6- 0	0.0	6- 0	0.0
7- 33	0.500	7- 7	-0.500	7- 0	0.0	7- 0	0.0	7- 0	0.0	7- 0	0.0
8- 6	0.0	8- 10	0.0	8- 9	0.0	8- 0	0.0	8- 0	0.0	8- 0	0.0
9- 8	0.0	9- 10	0.0	9- 17	0.0	9- 0	0.0	9- 0	0.0	9- 0	0.0
10- 4	0.0	10- 5	524.000	10- 8	0.0	10- 9	0.0	10- 16	-40.000	10- 17	-484.0
11- 3	0.0	11- 4	1500.000	11- 14	-1500.000	11- 15	0.0	11- 16	0.0	11- 0	0.0
12- 1	-3500.000	12- 3	2000.000	12- 13	1500.000	12- 0	0.0	12- 0	0.0	12- 0	0.0
13- 3	0.0	13- 12	-1500.000	13- 14	1500.000	13- 0	0.0	13- 0	0.0	13- 0	0.0
14- 11	1500.000	14- 13	-1500.000	14- 15	0.0	14- 0	0.0	14- 0	0.0	14- 0	0.0
15- 11	0.0	15- 14	0.0	15- 20	0.0	15- 21	0.0	15- 0	0.0	15- 0	0.0
16- 10	40.000	16- 11	0.0	16- 17	0.0	16- 20	-40.000	16- 0	0.0	16- 0	0.0
17- 9	0.0	17- 10	484.000	17- 16	0.0	17- 18	-484.000	17- 19	0.0	17- 0	0.0
18- 17	484.000	18- 19	0.0	18- 47	-484.000	18- 48	0.0	18- 0	0.0	18- 0	0.0
19- 17	0.0	19- 18	0.0	19- 20	0.0	19- 23	0.0	19- 26	0.0	19- 47	0.0
20- 15	0.0	20- 16	40.000	20- 19	0.0	20- 21	0.0	20- 23	-40.000	20- 0	0.0
21- 15	0.0	21- 20	0.0	21- 22	0.0	21- 0	0.0	21- 0	0.0	21- 0	0.0
22- 21	0.0	22- 0	0.0	22- 0	0.0	22- 0	0.0	22- 0	0.0	22- 0	0.0
23- 19	0.0	23- 20	40.000	23- 24	-40.000	23- 0	0.0	23- 0	0.0	23- 0	0.0
24- 23	40.000	24- 25	-40.000	24- 26	0.0	24- 0	0.0	24- 0	0.0	24- 0	0.0
25- 24	40.000	25- 26	0.0	25- 31	-40.000	25- 0	0.0	25- 0	0.0	25- 0	0.0
26- 19	0.0	26- 24	0.0	26- 25	0.0	26- 31	0.0	26- 45	0.0	26- 46	0.0
27- 28	0.0	27- 45	0.0	27- 46	0.0	27- 47	0.0	27- 0	0.0	27- 0	0.0
28- 27	0.0	28- 0	0.0	28- 0	0.0	28- 0	0.0	28- 0	0.0	28- 0	0.0
29- 30	-124.000	29- 38	0.0	29- 45	124.000	29- 0	0.0	29- 0	0.0	29- 0	0.0
30- 29	124.000	30- 31	-35.000	30- 39	-449.000	30- 45	360.000	30- 0	0.0	30- 0	0.0
31- 25	40.000	31- 26	0.0	31- 30	35.000	31- 32	-40.000	31- 42	-35.000	31- 43	0.0
32- 31	40.000	32- 33	0.0	32- 34	-40.000	32- 41	0.0	32- 42	0.0	32- 0	0.0
33- 32	0.0	33- 34	0.0	33- 7	0.500	33- 0	0.0	33- 0	0.0	33- 0	0.0
34- 32	40.000	34- 33	0.0	34- 35	-152.000	34- 40	112.000	34- 0	0.0	34- 0	0.0
35- 34	152.000	35- 36	0.0	35- 50	-152.000	35- 0	0.0	35- 0	0.0	35- 0	0.0
36- 35	0.0	36- 40	0.0	36- 0	0.0	36- 0	0.0	36- 0	0.0	36- 0	0.0
37- 39	0.0	37- 40	0.0	37- 0	0.0	37- 0	0.0	37- 0	0.0	37- 0	0.0
38- 29	0.0	38- 39	0.0	38- 0	0.0	38- 0	0.0	38- 0	0.0	38- 0	0.0
39- 30	449.000	39- 37	0.0	39- 38	0.0	39- 43	-77.000	39- 44	-372.000	39- 0	0.0
40- 34	-112.000	40- 36	0.0	40- 37	0.0	40- 41	112.000	40- 44	0.0	40- 0	0.0
41- 32	0.0	41- 40	-112.000	41- 42	112.000	41- 44	0.0	41- 0	0.0	41- 0	0.0
42- 31	35.000	42- 32	0.0	42- 41	-112.000	42- 43	77.000	42- 0	0.0	42- 0	0.0
43- 31	0.0	43- 39	77.000	43- 42	-77.000	43- 44	0.0	43- 0	0.0	43- 0	0.0
44- 39	372.000	44- 40	0.0	44- 41	0.0	44- 43	0.0	44- 0	0.0	44- 0	0.0
45- 26	0.0	45- 27	0.0	45- 29	-124.000	45- 30	-360.000	45- 46	484.000	45- 0	0.0
46- 26	0.0	46- 27	0.0	46- 45	-484.000	46- 47	484.000	46- 0	0.0	46- 0	0.0
47- 18	484.000	47- 19	0.0	47- 27	0.0	47- 46	-484.000	47- 0	0.0	47- 0	0.0
48- 18	0.0	48- 0	0.0	48- 0	0.0	48- 0	0.0	48- 0	0.0	48- 0	0.0
49- 1	-500.000	49- 3	0.0	49- 49	500.000	49- 0	0.0	49- 0	0.0	49- 0	0.0
50- 35	152.000	50- 50	-140.000	50- 0	0.0	50- 0	0.0	50- 0	0.0	50- 0	0.0

SECTION	TEMPERATURE (C)	VOLUME (10**6GAL)	DEPTH (FT)	WTEMP (LBS/DAY)
1	21.00	38148.00	55.00	1609486.00
2	21.00	6597.36	27.00	0.0
3	20.50	71089.88	25.00	0.0
4	21.00	23023.44	25.00	0.0
5	21.50	17376.04	28.00	0.0
6	21.50	31236.48	26.00	0.0
7	23.00	1959.76	25.00	76240.31
8	21.50	21048.71	20.00	0.0
9	21.50	6874.12	10.00	0.0
10	21.50	18445.68	25.00	0.0
11	21.50	19784.60	20.00	0.0
12	21.00	5213.56	16.00	0.0
13	21.00	5961.56	14.00	0.0
14	21.50	5093.88	12.00	0.0
15	21.50	5093.88	16.00	0.0
16	21.50	13426.60	29.00	0.0
17	21.50	13740.76	17.00	0.0
18	22.00	9200.40	13.00	0.0
19	22.00	13740.76	17.00	0.0
20	22.00	14967.48	23.00	0.0
21	22.00	4345.88	10.00	0.0
22	21.50	671.70	15.00	0.0
23	22.00	1855.04	18.00	0.0
24	22.00	2999.48	20.00	0.0
25	22.00	2326.28	15.00	0.0
26	22.00	4577.76	13.00	0.0
27	22.00	2094.40	7.00	0.0
28	22.00	160.07	3.00	0.0
29	22.50	7150.88	7.00	0.0
30	22.50	513.13	9.00	0.0
31	22.50	1136.96	18.00	0.0
32	23.00	2169.20	28.00	0.0
33	23.00	2049.52	27.00	0.0
34	23.00	1668.04	20.00	0.0
35	23.00	897.60	15.00	0.0
36	23.00	89.76	4.00	0.0
37	23.00	216.92	4.00	0.0
38	22.50	545.29	6.00	0.0
39	22.50	434.59	8.00	0.0
40	23.00	379.24	7.00	0.0
41	23.00	195.23	15.00	0.0
42	23.00	195.23	15.00	0.0
43	23.00	130.15	10.00	0.0
44	23.00	117.44	9.00	0.0
45	22.00	2707.76	10.00	0.0
46	22.00	2797.52	11.00	0.0
47	22.00	3904.56	12.00	0.0
48	22.00	1002.32	6.00	0.0
49	20.50	18326.00	38.00	0.0
50	23.00	964.92	17.50	38379.31

ITERATION NUMBER 78

SECTION	DECAY COEFFICIENT (1/DAY)	MATRIX DIAGONAL (MGD)	SOURCE LOADS (LBS/DAY)	BOD PROFILE (MG/L)
1	0.260	192040.438	1609486.000	1.50
2	0.260	43797.688	0.0	1.44
3	0.255	139002.438	0.0	0.35
4	0.260	44435.500	0.0	0.10
5	0.265	45350.840	0.0	0.03
6	0.265	31089.441	0.0	0.02
7	0.281	8348.344	76240.313	2.51
8	0.265	24714.410	0.0	0.02
9	0.265	6126.117	0.0	0.10
10	0.265	27550.031	0.0	0.11
11	0.265	35290.488	0.0	0.20
12	0.260	28161.863	0.0	1.12
13	0.260	15859.039	0.0	0.49
14	0.265	13147.836	11050.000	0.35
15	0.265	11528.059	0.0	0.29
16	0.265	30049.996	0.0	0.22
17	0.265	27569.813	0.0	0.24
18	0.270	15508.391	0.0	0.55
19	0.270	25961.988	0.0	0.64
20	0.270	27246.191	0.0	0.44
21	0.270	9649.863	0.0	0.32
22	0.265	252.454	0.0	0.09
23	0.270	16657.863	0.0	1.19
24	0.270	19830.801	0.0	1.45
25	0.270	15954.508	0.0	2.19
26	0.270	18895.805	0.0	1.91
27	0.270	6351.238	0.0	1.52
28	0.270	1489.579	0.0	1.47
29	0.276	15024.902	0.0	2.72
30	0.276	23508.664	0.0	4.02
31	0.276	21829.250	0.0	3.48
32	0.281	25473.953	0.0	3.74
33	0.281	11694.844	0.0	3.16
34	0.281	48663.238	0.0	3.73
35	0.281	22172.180	0.0	3.56
36	0.281	1752.249	0.0	4.20
37	0.281	1672.587	0.0	4.53
38	0.276	4108.711	0.0	3.47
39	0.276	23414.109	0.0	4.93
40	0.281	19360.543	0.0	4.58
41	0.281	23696.078	0.0	5.49
42	0.281	27207.582	0.0	5.01
43	0.281	19826.578	0.0	5.19
44	0.281	9007.582	350000.000	9.69
45	0.270	22261.113	0.0	2.32
46	0.270	18364.355	0.0	1.81
47	0.270	12401.383	0.0	1.15
48	0.270	1518.558	0.0	0.45
49	0.255	208299.125	0.0	0.42

ITERATION NUMBER 76

SECTION	DEOXYGENATION COEFFICIENT (1/DAY)	REAERATION COEFFICIENT (1/DAY)	MATRIX DIAGONAL (MGD)	SOURCE LOADS (MGD*MG/L)	PHOTO MINUS RESPIRATION (MG/(L-DAY)	BOTTOM DEMAND (GM/M**2/DAY)	DISSOLVED OXYGEN DEFICIT (MG/L)
1	0.260	0.204	189904.125	285768.688	0.0	0.0	2.32292557
2	0.260	0.204	43428.234	2478.215	0.0	0.0	2.30799961
3	0.255	0.202	135237.500	6311.887	0.0	0.0	0.65726358
4	0.260	0.204	43146.188	606.600	0.0	0.0	0.22506475
5	0.265	0.206	44323.578	142.175	0.0	0.0	0.07670677
6	0.265	0.206	29242.758	127.923	0.0	0.0	0.05624691
7	0.281	0.212	8213.172	20599.313	0.0	0.0	4.14091587
8	0.265	0.206	23470.020	113.118	0.0	0.0	0.06964254
9	0.265	0.206	5719.723	181.091	0.0	0.0	0.24360746
10	0.265	0.206	26459.535	530.384	0.0	0.0	0.24850088
11	0.265	0.206	34120.832	1047.580	0.0	0.0	0.39897430
12	0.260	0.204	27869.902	1515.402	0.0	0.0	1.83722687
13	0.260	0.204	15525.191	761.558	0.0	0.0	0.91585374
14	0.265	0.206	12846.688	473.727	0.0	0.0	0.53069276
15	0.265	0.206	11226.910	398.150	0.0	0.0	0.55264324
16	0.265	0.206	29256.223	776.959	0.0	0.0	0.42942035
17	0.265	0.206	26757.465	863.794	0.0	0.0	0.44087487
18	0.270	0.208	14935.020	443.277	0.100	0.0	0.71190506
19	0.270	0.208	25105.660	994.020	0.100	0.0	0.84716666
20	0.270	0.208	26313.414	300.148	0.100	0.0	0.67135566
21	0.270	0.208	9379.027	372.676	0.0	0.0	0.58591163
22	0.265	0.206	212.743	16.635	0.0	0.0	0.28296572
23	0.270	0.208	16542.258	411.942	0.100	0.0	1.41017532
24	0.270	0.208	19643.871	1172.424	0.0	0.0	1.62614822
25	0.270	0.208	15809.535	1379.148	0.0	0.0	2.06098557
26	0.270	0.208	18610.516	2360.644	0.0	0.0	1.89990330
27	0.270	0.208	6220.715	-1024.692	0.900	0.0	1.33306503
28	0.270	0.208	1479.603	-80.226	0.900	0.0	1.24883366
29	0.276	0.210	14555.773	5367.355	0.0	0.0	2.49452400
30	0.276	0.210	23475.000	569.473	0.0	0.0	2.56293869
31	0.276	0.210	21754.660	1092.085	0.0	0.0	2.57160473
32	0.281	0.212	25324.332	2283.427	0.0	0.0	3.14335251
33	0.281	0.212	11553.480	1820.952	0.0	0.0	3.57471657
34	0.281	0.212	48548.184	1751.564	0.0	0.0	3.27741241
35	0.281	0.212	22110.266	899.268	0.0	0.0	3.33720779
36	0.281	0.212	1746.057	106.101	0.0	0.0	3.22724342
37	0.281	0.212	1657.625	276.370	0.0	0.0	3.05498028
38	0.276	0.210	4072.938	521.066	0.0	0.0	2.61530781
39	0.276	0.210	23385.602	591.210	0.0	0.0	2.65928745
40	0.281	0.212	19334.387	488.154	0.0	0.0	3.14212322
41	0.281	0.212	23682.613	301.173	0.0	0.0	2.94902229
42	0.281	0.212	27194.117	274.853	0.0	0.0	2.84555054
43	0.281	0.212	19817.602	189.982	0.0	0.0	2.76127529
44	0.281	0.212	8999.480	320.030	0.0	0.0	2.77995682
45	0.270	0.208	22092.367	1696.422	0.0	0.0	2.12695313
46	0.270	0.208	18190.012	1369.563	0.0	0.0	1.82706547
47	0.270	0.208	12158.047	828.402	0.100	0.0	1.29961205
48	0.270	0.208	1456.093	-880.303	1.000	0.0	0.00537058
49	0.255	0.202	207328.563	1980.266	0.0	0.0	0.71596408

50	0.281	0.212	6345.523	8753.598	0.0	0.0	3.53402615
1	0.15035E 05	0.21000E 02	0.23229E 01	0.70694E 01	0.47465E 01		
2	0.15035E 05	0.21000E 02	0.23080E 01	0.70694E 01	0.47614E 01		
3	0.15371E 05	0.20500E 02	0.65726E 00	0.70446E 01	0.63873E 01		
4	0.15128E 05	0.21000E 02	0.22506E 00	0.70625E 01	0.68375E 01		
5	0.15131E 05	0.21500E 02	0.76707E-01	0.70623E 01	0.69856E 01		
6	0.14762E 05	0.21500E 02	0.56247E-01	0.70895E 01	0.70332E 01		
7	0.13616E 05	0.23000E 02	0.41409E 01	0.71738E 01	0.30328E 01		
8	0.14773E 05	0.21500E 02	0.69643E-01	0.70886E 01	0.70190E 01		
9	0.14793E 05	0.21500E 02	0.24361E 00	0.70871E 01	0.68435E 01		
10	0.14961E 05	0.21500E 02	0.24850E 00	0.70748E 01	0.68263E 01		
11	0.15044E 05	0.21500E 02	0.39897E 00	0.70687E 01	0.66697E 01		
12	0.15124E 05	0.21000E 02	0.18372E 01	0.70628E 01	0.52256E 01		
13	0.15269E 05	0.21000E 02	0.91585E 00	0.70522E 01	0.61363E 01		
14	0.15077E 05	0.21500E 02	0.53069E 00	0.70662E 01	0.65355E 01		
15	0.14735E 05	0.21500E 02	0.55264E 00	0.70914E 01	0.65388E 01		
16	0.14817E 05	0.21500E 02	0.42942E 00	0.70854E 01	0.66560E 01		
17	0.14752E 05	0.21500E 02	0.44087E 00	0.70902E 01	0.66493E 01		
18	0.14437E 05	0.22000E 02	0.71191E 00	0.71133E 01	0.64014E 01		
19	0.14423E 05	0.22000E 02	0.84717E 00	0.71144E 01	0.62672E 01		
20	0.14559E 05	0.22000E 02	0.67136E 00	0.71044E 01	0.64330E 01		
21	0.14654E 05	0.22000E 02	0.58591E 00	0.70974E 01	0.65115E 01		
22	0.14654E 05	0.21500E 02	0.28297E 00	0.70974E 01	0.68144E 01		
23	0.14217E 05	0.22000E 02	0.14102E 01	0.71296E 01	0.57194E 01		
24	0.14125E 05	0.22000E 02	0.16261E 01	0.71363E 01	0.55102E 01		
25	0.13932E 05	0.22000E 02	0.20610E 01	0.71505E 01	0.50895E 01		
26	0.13992E 05	0.22000E 02	0.18999E 01	0.71461E 01	0.52462E 01		
27	0.14000E 05	0.22000E 02	0.13331E 01	0.71455E 01	0.58124E 01		
28	0.14000E 05	0.22000E 02	0.12488E 01	0.71455E 01	0.58967E 01		
29	0.13735E 05	0.22500E 02	0.24945E 01	0.71651E 01	0.46705E 01		
30	0.13624E 05	0.22500E 02	0.25629E 01	0.71732E 01	0.46103E 01		
31	0.13686E 05	0.22500E 02	0.25716E 01	0.71686E 01	0.45970E 01		
32	0.13515E 05	0.23000E 02	0.31434E 01	0.71812E 01	0.40379E 01		
33	0.13526E 05	0.23000E 02	0.35747E 01	0.71804E 01	0.36057E 01		
34	0.13472E 05	0.23000E 02	0.32774E 01	0.71843E 01	0.39069E 01		
35	0.13433E 05	0.23000E 02	0.33372E 01	0.71872E 01	0.38500E 01		
36	0.13439E 05	0.23000E 02	0.32272E 01	0.71868E 01	0.39596E 01		
37	0.13472E 05	0.23000E 02	0.30550E 01	0.71843E 01	0.41294E 01		
38	0.13654E 05	0.22500E 02	0.26153E 01	0.71710E 01	0.45557E 01		
39	0.13530E 05	0.22500E 02	0.26593E 01	0.71801E 01	0.45208E 01		
40	0.13441E 05	0.23000E 02	0.31421E 01	0.71867E 01	0.40445E 01		
41	0.13419E 05	0.23000E 02	0.29490E 01	0.71883E 01	0.42393E 01		
42	0.13486E 05	0.23000E 02	0.28456E 01	0.71833E 01	0.43378E 01		
43	0.13491E 05	0.23000E 02	0.27613E 01	0.71830E 01	0.44217E 01		
44	0.13111E 05	0.23000E 02	0.27800E 01	0.72109E 01	0.44310E 01		
45	0.13852E 05	0.22000E 02	0.21270E 01	0.71564E 01	0.50295E 01		
46	0.13964E 05	0.22000E 02	0.18271E 01	0.71481E 01	0.53211E 01		
47	0.14163E 05	0.22000E 02	0.12996E 01	0.71335E 01	0.58339E 01		
48	0.14437E 05	0.22000E 02	0.53706E-02	0.71134E 01	0.71080E 01		
49	0.15377E 05	0.20500E 02	0.71596E 00	0.70442E 01	0.63282E 01		
50	0.13273E 05	0.23000E 02	0.35340E 01	0.71990E 01	0.36650E 01		